



*"The rocks are the final court of appeal" Francis Pettijohn*

# **PRECAMBRIAN RESEARCH CENTER**

## **PLANNING DOCUMENT**

**A collaborative teaching and research center  
providing training and support in Precambrian field  
studies for the next generation of geoscientists**



**NATURAL RESOURCES  
RESEARCH INSTITUTE**



**The University of Minnesota Duluth**

**Natural Resources Research Institute**

**Minnesota Geological Survey**

## Precambrian Research Center

### EXECUTIVE SUMMARY

Geology is the study of the Earth, and every geologist should be skilled in observing the Earth. Such observations are the result of geologic mapping, which lays the foundation upon which all fields of geologic endeavor are built. Yet, the teaching of geologic mapping in academic institutions has dramatically declined over the past couple decades as the ever-expanding scope of the geosciences has expanded into many subdisciplines, many strictly laboratory-based. As well, great advances in economic geology in the 1960s, 1970s, and 1980s led to advanced understanding the origin of many ore deposit types, which consequently led to the discovery of hundreds of large ore deposits exposed at or near the Earth's surface due to geological field studies. As a result of these discoveries, metal prices remained essentially stable (i.e. low) for decades, mineral exploration expenditures remained low, and few private sector jobs were available for geologists skilled in geological mapping.

A new demand for geoscientists skilled in geological mapping is largely being fueled by the increased resource demands created by industrial growth in China and the rest of Asia in conjunction with depletion of ore reserves and/or closing of major metal mines. Well-trained geologists are needed in the private sector due to increased activities of mineral exploration and mining companies, both locally and internationally, as they seek to find and develop new ore deposits to meet the increased global resource demand. Another source of this increased demand comes from the public sector (academic research institutes, geologic surveys, and local government agencies) with the aging of geoscientists with field expertise. The proposed Precambrian Research Center (PRC) is being initiated at UMD to primarily satisfy the urgent, long-term demand for, and critically low supply of, geoscientists skilled in geological mapping and map-making.

The mission of the PRC will be to provide training and support to the next generation of geoscientists in modern methods of geological mapping and map-making. This training will focus on the unique attributes of mapping the ancient Precambrian rocks of the southern Canadian Shield. The Canadian Shield and similar terranes on every continent are host to many of the world's premier ore deposits.

The goals of the PRC are threefold:

- to provide advanced training for upper level undergraduate students, graduate students, and professional geologists in advanced techniques and modern methods of mapping and map-making in glaciated Precambrian terrains
- to attract and provide financial assistance to outstanding students who have an interest in conducting field-oriented graduate research at UMD on Precambrian geology of the Lake Superior region
- to assist PRC-trained students in finding employment in the public and private sector

The PRC will accomplish these goals through five basic programmatic components:

1. Summer Precambrian geology field camp in northeastern Minnesota
2. Student research assistantships and grants
3. Professional workshops and field trips
4. Upper level geology courses at UMD
5. Additional education, outreach, mentoring, and student career planning activities

The primary beneficiaries of the PRC's programs will be:

- Geology Students – through training in highly marketable field mapping skills and education in other topics related to Precambrian geology and through financial support of graduate and undergraduate research projects;
- Minerals Industry – through continuing education opportunities in advanced topics related to field mapping and map-making, through collaborations and partnerships with public-sector geoscientists, and through access to a pool of students who are well-trained in field methods and related subjects important to mineral exploration;
- Geological Surveys – through collaborations in mapping activities throughout the Lake Superior region and through access to field-trained students who will be needed to replenish and possibly grow aging survey staffs;
- University of Minnesota – through the creation of a high quality educational program with strong financial support that will enhance the already exemplary reputation UMD has within the global geoscience community for producing field-savvy students and that will attract new graduate and undergraduate students to UMD’s geology program; and
- State of Minnesota – through developing public-private partnerships between the state, university, and the minerals and mining industries that will grow jobs in the state in an environmentally responsible manner.

A preliminary business plan for the PRC has been developed which considers:

- Organizational Structure - consideration of the PRC’s financial, human resource, and programmatic relationship with its three host institutions (Natural Resources Research Institute, the Department of Geological Sciences, and the Minnesota Geological Survey) and its collaborating institutions;
- Benefactors – identifying the main financial benefactors to the PRC and what their target contributions to its success should be;
- Marketing Strategy – development of ways to make potential clients and benefactors aware of our “product”; and
- Budget Plan – estimating probable expenditures and needed income to create a workable and reasonable budget for the first three years of the PRC.

A preliminary model of the PRC has generated enthusiastic support of its basic objectives from the geological community in the U.S. and Canada, including executives and geoscientists within the minerals industry, geological surveys, geological societies, and academia. In addition, three preeminent geoscientists have agreed to form the initial core of outside advisors for the PRC Advisory Board.

If the vision of the PRC is fully realized, it will be without peer among academic institutions anywhere in the world. The PRC’s sponsorship of a full-time summer field camp exclusively devoted to the geology of Precambrian rocks will be unique. Moreover, although a number of academically affiliated research institutes include field studies of Precambrian terrains in their programs, this is not the primary focus of these organizations. For most of them, the primary emphasis is the study of ore deposits, many of which happen to occur in Precambrian rocks. The PRC will specialize in training students and professional geologists in a skill that is rapidly being lost, but is fundamental to all geologic activities – how to map.

More detailed information about the PRC can be found in the following report. Your support and approval of the PRC can be indicated with your signature below.

## APPROVALS and CERTIFICATIONS

The information provided in the accompanying proposal is correct to the best of my knowledge. In the event this application is awarded, I (we) agree to abide by all applicable institutional and sponsoring agency policies and procedures including the Intellectual Property Policy of the University of Minnesota and to follow commonly accepted scientific practices in recording and maintaining records of research.

I (we) certify that I (we) have read the University of Minnesota Code of Conduct policy and agree to abide by the rights and responsibilities as identified therein.

Signature \_\_\_\_\_  
Dean M. Peterson James D. Miller Date  
Co-directors

**We certify that the above statements are correct to the best of our knowledge. The commitment of departmental and collegiate resources, if any, has been noted and approved. We agree that the scientific objectives of this application are in keeping with departmental and collegiate goals.**

Signature \_\_\_\_\_  
Michael Lulich, Director, Natural Resources Research Institute (NRRI) Date

Signature \_\_\_\_\_  
James Riehl, Dean, College of Science and Engineering Date

Signature \_\_\_\_\_  
Donald Fosnacht, Director, Center for Applied Research and Technology Development (NRRI) Date

Signature \_\_\_\_\_  
Penny Morton, Chair, Department of Geological Sciences Date

Signature \_\_\_\_\_  
Harvey Thorleifson, Director, Minnesota Geological Survey Date

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# 1. INTRODUCTION

Geology uses a variety of tools to study the earth. However, the basis for every type of geologic study is fundamentally rooted in observations made of rocks in their natural habitat – in the “field”. An intimate understanding of the fundamentals of field geology gives geologists an appreciation of the coherent and compelling field-based scientific arguments from which all other interpretations grow. All the great concepts in geology that spawned major scientific revolutions, e.g., geologic time, the rock cycle, principle of faunal succession, plate tectonic theory, snowball earth theory, were ideas generated from making basic observations of geological relationships in the field. In many respects, the validity of future advances in the geological sciences depends on the fundamental geologic principles best learned and understood in the field. The renowned stratigrapher Francis Pettijohn (U of MN geology alum and author of “The Unrepentant Field Geologist”) said it best when he stated - “the rocks are the final court of appeal”. We have incorporated those words into our logo as a constant reminder of that basic truth.

The objective of field geology is to document the occurrence and spatial relationships of bedrock and unconsolidated sediments exposed at the earth’s surface, as well as projecting these data into unexposed areas on the surface and at depth into the subsurface where direct observation is impossible. From this documentation, geologists make interpretations about the geologic processes and events that occurred in the past and make predictions about where various earth resources might be found, and where and when geologic hazards might occur in the future. The most fundamental way this information is documented, interpreted, and conveyed to others is by the creation of geologic maps. A geologic map groups rocks or sediments, which are interpreted to have formed at the same time and by a similar process, into geologic units or formations. The maps include explanations that describe the range of characteristics of the rocks within each unit and their spatial and temporal relationship to other rock units. They also include information about how the rocks may have been deformed by folding and faulting.

Although geologic maps include information that is factual, such as the locations of bedrock exposures (outcrops) and the orientations of structures in the rocks, geologic maps are largely interpretive on many scales. On the outcrop scale, the rock may be too fine-grained to determine its composition, or the exposure may be too coated with lichen or moss to see the rock clearly. Since a sample cannot be taken of every rock occurrence and studied in the lab, the field geologist must make his/her best estimate of what the rock is. On the map scale, vast areas of bedrock may be buried beneath unconsolidated material (usually glacial till in Minnesota) leaving only a few outcrops as clues to the buried geology. Even in relative well exposed areas (maybe 20% of the bedrock surface being exposed), geologic contacts or faults may not be exposed and must be inferred. Then too, the process of grouping of rocks into common units that infer similar age and process can become an iterative and interpretive exercise in lumping and splitting among rocks that commonly span a range of types. In the end, a geologic map must be considered an interpretive work of art based on some facts, quite a bit of inference, and lots of best guesses. Its final appearance is largely an interpretation that critically depends on the biases and experiences of the geologists doing the mapping. Among field geologists, a common refrain is “the one who’s seen the most rocks wins”.

Despite a general recognition of the primacy of field geology in the earth sciences, the training of students in the methodologies (and uncertainties) of geologic mapping and map-making has steadily declined in academia for decades to the point where it is quickly becoming a lost art. To quote some prominent geologists:

“We are perilously close to having people out there in control of all types of geological endeavors who cannot read the rocks.”

*Bruce A. Marsh, Professor of Geology, Johns Hopkins University*

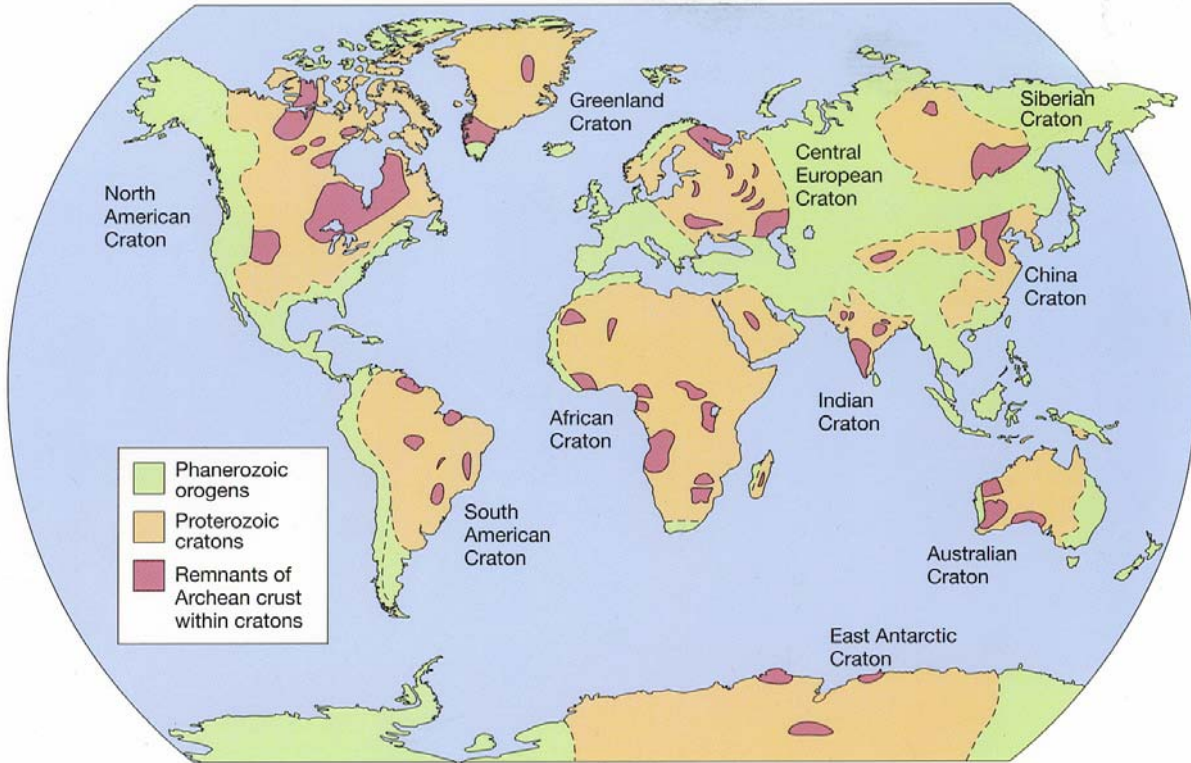
“Current university staff must train the succeeding generations who will populate the universities, for once field skills are lost within academia, it will be extremely difficult to recapture them. Thus time is of the essence, and it is very important to support centers where the skills are still preserved before existing staff retire and are replaced by those lacking the skills”.

*Anthony J. Naldrett, Emeritus Professor of Geology, University of Toronto.*

The discipline of geologic field mapping is experience-based; it cannot be taught from a book. Rather, the best teachers of field mapping are active professional field geologists who continue to hone their field skills through to retirement and beyond. The dissemination of multifaceted field skills from active professional geologists acting as mentors to young geoscientists has always been one of the most important educational experiences of geologists. In the past, these mentors included senior personnel from the mining, mineral exploration, and petroleum industries, experienced staff from state and federal geological surveys, and faculty from colleges and universities. However, over the last few decades the role of the geologic field mentor to young geoscientists has been dramatically diminished. The lack of field-based mentors is a function of many factors, including: (1) the globalization and cyclic nature of the mineral and petroleum industry; (2) budget cuts at state and federal geological surveys; and (3) the expanding scope of the geosciences away from the field into the laboratory (partially based on advances in technology and new theoretical concepts). These three factors have led to fewer and fewer students choosing careers in economic geology and related hard rock fields, and many geoscience departments throughout the U.S. have been shortening or dropping courses and whole programs in minerals-related topics like economic geology, field methods, mineralogy, igneous and metamorphic petrology, and structural geology. All of these factors have had a profound negative impact on the discipline of geologic mapping.

The only exposure to geological mapping that most geology students in the U.S. get is during a six-week summer field camp, typically in the Rocky Mountains, between their junior and senior years of undergraduate education. In fact, 136 of the 151 field locations where accredited summer geology field camps are held occur in Rocky Mountain states (see Fig. 6). The number of summer field camps has actually been declining over the years as more and more schools are not requiring field camp for a B.S. degree. While openness, relief, and good exposure of the Rocky Mountains is ideal for teaching basic principles of field mapping, the style of mapping and the type of geology emphasized at these camps do not translate directly to other types of geological terrains in other parts of the world. One very distinctive group of terrains is continental shields, which are the exposed ancient cores (cratons) of all continents (Fig. 1). Continental shields are composed of a complex mix of rocks of Precambrian age (>540 million years), which tell the early history of how each continent was constructed. Moreover, Precambrian shields host a large percentage of the major ore deposit of the world. Minnesota lies at the southern margin of the vast, low-lying Canadian Shield (see Fig. 6), which has the added complication that it had been extensively modified and partially buried by glacial action over the past 2 million years. Mapping the glaciated Precambrian geology of the Canadian Shield requires a very unique skill set from what is typically taught in Rocky Mountain field camps (see below).

This dearth of well-trained field geologists comes at a very inopportune time as there is currently a strong and growing demand for geoscientists with expertise in field mapping, especially of Precambrian terrains. This demand is evident in both the public and private sectors and both globally and locally, but it is especially urgent in the minerals exploration industry. Because of the pressure on global resource caused by the economic recovery of Western countries and rapid growth of China and other Asian economies, mineral exploration companies are gearing up for a dramatic and protracted growth in order to find new mineral resources.



**Figure 1.** Precambrian cratons of the world. Continental shields are the exposed portions of the cratons and are composed of two ages of Precambrian rocks: Archean (>2.5 billion years) and Proterozoic (2.5-0.5 billion years).

## 2. MISSION, GOALS, AND BENEFICIARIES

The Precambrian Research Center (PRC) has been conceived with the purpose of satisfying part of that urgent need for well-trained field geologists in both the public and private sectors. The PRC will accomplish this by gathering a consortium of field-experienced geoscientists with the common goal of mentoring the next generation of field geologists in the art and science of geologic mapping of Precambrian age rocks. The PRC will be based at UMD under the guidance of the Department of Geological Sciences and the Natural Resources Research Institute (NRRI), and in collaboration with the Minnesota Geological Survey (MGS) and many regional colleges, universities, and government geoscience agencies. The affiliation with the Department of Geological Sciences will build upon the long-standing reputation the department has for producing field-trained students knowledgeable in Precambrian geology and related fields. The PRC's affiliation with the NRRI will be aided by its strong connections with the public sector for purposes of fund-raising for and job placement of PRC-supported students.

The Precambrian Research Center (PRC) is to be established as a consortium of professional field geologists and university faculty whose mission is to:

*Provide training and support in Precambrian field studies  
for the next generation of geoscientists.*

The primary goals of the PRC are:

- to provide advanced training for upper level undergraduate students, graduate students, and professional geologists in advanced techniques and modern methods of mapping and map-making in glaciated Precambrian terrains;
- to attract and provide financial assistance to outstanding students who have an interest in conducting field-oriented graduate research at UMD on Precambrian geology of the Lake Superior region; and
- to assist PRC-trained and supported students in finding employment in the public and private sector.

The center will seek to accomplish these goals through five basic program components:

- 1) Summer Precambrian geology field camp in northeastern Minnesota;
- 2) Scholarships for field-oriented graduate research at UMD;
- 3) Workshops and short-courses on applied Precambrian field studies and geologic map-making;
- 4) Upper level course offerings at UMD on field methods and digital geologic map-making;
- 5) Other education, outreach, mentoring and career planning programs.

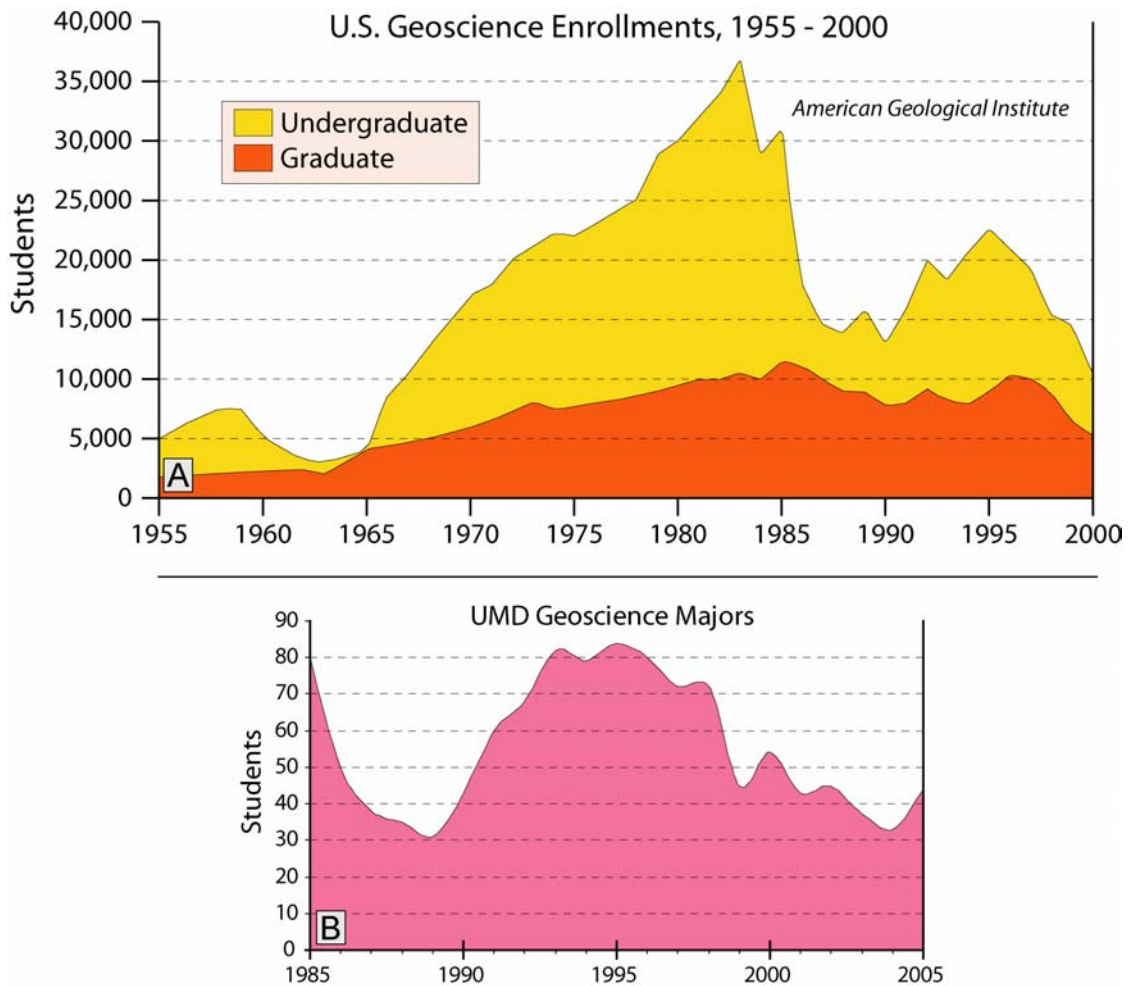
The rationale for developing the PRC is to satisfy the needs of five types of clientele - geology students (graduate and undergraduate), the minerals industry, geological surveys, the University of Minnesota, and the State of Minnesota. These clients will serve not only as the beneficiaries of the PRC, but will also serve as its benefactors (see section 4.2). Described below are the ways in which these different client groups will interact with and benefit from the PRC.

## **2.1 *Geology Students***

Changes in university student enrollments in specific major fields (such as the geosciences) have always resulted in a direct, but lagging response to changes in employment cycles and career opportunities. Enrollments generally track two to three years behind shifts in workforce patterns. Yet, by the time it takes students to achieve even threshold credentials for employment, hiring patterns have often shifted. Students may feel betrayed and leave the field. By the time the next hiring frenzy occurs, there may not be enough students in the pipeline to meet employment demands. Thus, in addition to the boom-bust cycles in employment, enrollments and employment opportunities are usually out-of-phase. Since 1952, the American Geological Institute (AGI) has tracked geoscience enrollment patterns (Fig. 2a). The steady climb to the highest enrollment levels (1965 to 1983) was due in large part to the tremendous and stable growth that occurred in the petroleum sector. From that 1983 peak, enrollment levels have gone through a net decline, with mixed enrollment rises and declines, and more recently a continued decline since 1996. From 1983 to 2000, there has been a 66.8% decline in geoscience enrollments nationwide. Since 1985, enrollment of undergraduate students majoring in the geosciences at the University of Minnesota Duluth has followed the national trends (Fig. 2b).

Geoscience employment over the past 15 years has undergone several significant changes. Traditional employment patterns have shifted in complexion among employer sectors as well as quantitatively. In the late 1980s and early 1990s, the major thrust of employment opportunities shifted from oil and gas to environmental consulting firms. Since the latter half of the 1990s, however, employment in oil and gas has been making a slight comeback; at the same time, non-traditional employment sectors have been expanding. Mining and mineral exploration companies are facing a critical juncture, as fewer students are graduating with geology degrees, and those that do have chosen career paths in the environmental sector. The federal government faces a general slowing, if not a freeze, of its hiring activity, while at the same time it is being asked to do more in the way of greater environmental vigilance, mostly through stricter

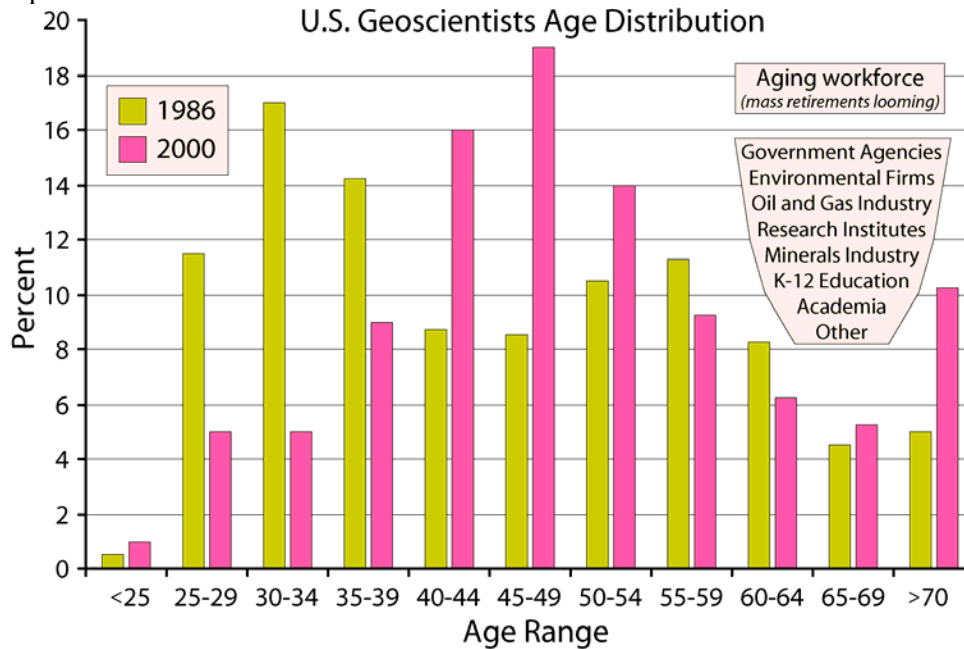
regulation. Those activities will result in greater outsourcing to environmental contractors. State geological surveys face similar economic tightening in the face of projected increases in environmental and related responsibilities. Almost all of the national laboratories require a Ph.D. for employment, and turnover is very low. Environmental consulting firms are likely to increase their hiring, due to federal and state government outsourcing, and in helping businesses meet environmental regulations or in siting new businesses. Employment at the college and university level is almost entirely done at the Ph.D. level, and most of the current job openings are at the non-tenure track or adjunct level. It is in K-12 science education where there is a demonstrated and severe shortage of qualified earth-science teachers. In 2000, the AGI conducted a Demographic and Compensation Survey of North American Geoscientists, and the results from that survey are compared to an earlier AGI survey, the North American Survey of Geoscientists (1986), in Figure 3. The demographics suggest that the geoscience workforce is aging at such a rate that the coming wave of retirements over the next 5 to 10 years will severely strain the projected pipeline levels, and there will be many more geoscience jobs available than there are students to fill them. Companies may well have to meet their needs by hiring from other physical sciences.



**Figure 2.** Trends in college-level geoscience enrollments at the national and local (UMD Department of Geological Sciences) levels. National data from the American Geological Institute.

In spite of all the uncertainties and complexities presented above, no other physical-science discipline is as tied to such a variety of real-world factors as the geosciences. Consider that the following conditions all affect the enrollments and employment of geoscientists: national interests and security, including the

price of oil, the price of metals and strategic minerals, access to global markets, and levels of federal funding; informed national awareness, including assessment, mitigation, and remediation of hazardous-waste sites, groundwater, and geohazards; population demographics, including the aging of the population, and the current and future composition of the workforce by gender, ethnic-minority status, and citizenship.

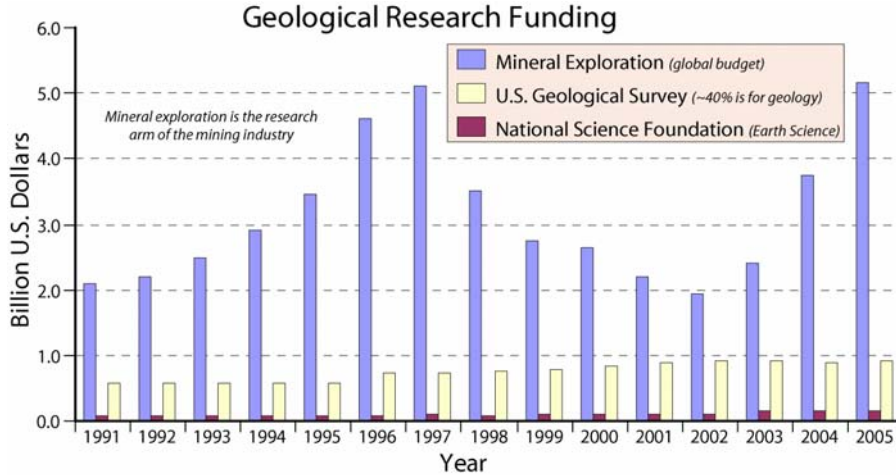


**Figure 3.** Aging trends of geoscientists employed in the United States. Data from the American Geological Institute.

One of the objectives of the PRC is to reinvigorate the role of geological mapping in geoscience education by giving students the opportunity to learn these required skills from a group of outstanding field geologists. In addition, these skills give students a jump-start on their careers as they move onto graduate school or careers in industry, geologic surveys, or academia.

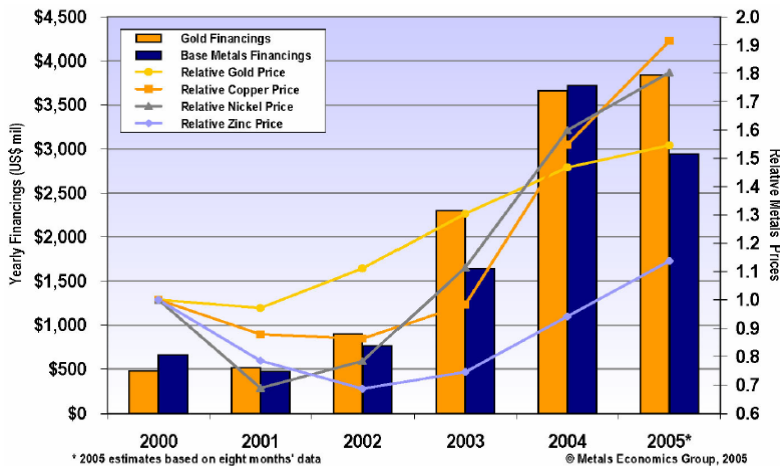
## 2.2 Minerals Industry

The mineral industry is, in the most fundamental breakdown, a two-tiered enterprise, mineral exploration and mining. Mineral exploration is the research activity of the mining industry, and private funding for these geological research programs far exceeds public sector-funded basic and applied geological research (Fig. 4). Total investment in the global mining industry's project pipeline was \$137 billion in 2005. These privately-funded research programs are fundamentally different from most public sector geological research in that the scientists have the ability to effectively test their hypotheses through diamond drilling programs into the subsurface. Mineral exploration begins with a geoscientist's idea, vision, or intuitive thought that is evaluated through repeated phases of data gathering (geological mapping, geochemical and geophysical surveying, drilling) and interpretation. Each program may involve years of costly work that, despite the improved tools of science and technology, remains a high-risk activity. Mineral exploration relies not only on the acquisition and interpretation of geologic information, but also on the knowledge of global economics, mineral economics, new exploration techniques, and an understanding of the social and political conditions of the regions explored. Although the effectiveness of any mineral exploration program depends in part on luck, its true strength depends primarily on decisions made by highly experienced field geologists.



**Figure 4.** Public (USGS and NSF) versus private (Mineral Exploration Companies) funding of geological research over the last fifteen years. (Data from USGS, NSF and the Metals Economic Group)

The current high demand for field geologists comes largely from the resurgent mineral exploration and mining industry, locally and globally. “We can’t find any qualified people” has come to be a commonly heard refrain from the minerals industry as they seek to find field-trained geologists to hire for careers in the mining and mineral exploration industry. Fueling this increase in exploration is the global recovery from a 15-20 year depression in metal prices (Fig. 5) that is itself triggered by economic recovery in the West and the rapid industrialization in China. After including India and Southeast Asia, a total of three billion people are going through an industrial revolution. By all accounts, this revolution will last into the foreseeable future (the level of metal consumption in China is forecast to grow by more than 80% over the next decade) and has driven up the worldwide demand for virtually all natural resources, of which the mineral industry supplies metals and mineral products. The need for qualified geologists with exceptional field skills has never been more profound for the industry, as the easy-to-find mineral deposits (exposed on the surface) throughout the world have largely already been discovered. Future mineral deposit discoveries will rely on geologists that have the ability to envision the Earth and geologic phenomena in four-dimensions, and use their field skills to predict the location of mineral deposits hidden beneath the Earth’s surface. In mining, the increased demand for mineral products has fueled the need for extending the life of existing mining properties. Moreover, new technologies, such as fuel cells and specialty steel, are increasing interest in formerly low-demand metals like platinum, palladium, and titanium.



**Figure 5.** Increase in budgets for gold and base metal exploration (bars) related to increased metal prices (relative to average 2000 prices)

The PRC will help the minerals industry in three ways: (1) by supplying the local and global minerals industry with well-educated young geoscientists that have had the opportunity to develop exceptional field mapping skills; (2) by developing and supervising graduate-level research projects (with industry sponsorship) on potentially economically significant mineral occurrences in the Lake Superior region; and (3) by funding graduate student research on topics important to the industry.

### **2.3 Geological Surveys**

State, provincial, and federal geological surveys play an important role in society by providing reliable scientific information to describe and understand the Earth; minimizing loss of life and property from natural disasters; managing water, biological, energy, and mineral resources; and enhancing and protecting our quality of life. These agencies rely on highly qualified staff to complete their missions, and outstanding field geologists form an essential component in the framework of these organizations. Although most of the job potential for Precambrian geological mappers exists in the minerals industry, the aging demographic trend (Fig. 3) of the geoscience workforce is probably most profound in the public sector's national and state/provincial surveys and local government entities dealing with land use issues. The need for continued geologic mapping throughout the U.S. has been confirmed by no less an authority than the U.S. Congress with its passage of the National Geologic Mapping Act of 1992. During hearings leading up to the reauthorization of that act in 1999, it was pointed out that less than 25% of 7.5-minute quadrangles in the U.S., which are at the standard 1:24,000 scale of geological mapping, had been completed. In the 14 years since the passage of the National Geologic Mapping Act, over 7,500 geologic maps have been produced ([www.doi.gov/oc/2005](http://www.doi.gov/oc/2005)). Many state surveys have benefited from new mapping initiatives the United States Geological Survey (USGS) has implemented in response to the legislation, few more so than the MGS.

The MGS mapping productivity has increased greatly due in large part to its involvement with the USGS's STATEMAP program over the past 11 years. This cost-sharing program and the related EDMAP program, which supports mapping by academic institutions, are both components of the National Cooperative Geologic Mapping Program, which grew out of this legislation. Bedrock and surficial map production at the MGS has increased at a phenomenal rate due to support from the STATEMAP program and from various state and local agencies (particularly the County Atlas Program). Between 1962 and 1990, the MGS had produced about 50 bedrock and surficial geologic maps through its Miscellaneous Map Series (up to M-67). In the past 15 years, the MGS has produced nearly 100 geologic maps. This increased output of geologic maps was accomplished with no new hires at the MGS - the staff simply has become more experienced and more productive. Despite this increased map coverage, much more of the surficial and bedrock geology of state remains to be mapped in adequate detail, a task that will take many decades even if the MGS staff were increased.

Despite this increased local and national push to provide more mapping coverage, the reality is that the national and state surveys have been either downsized or kept staffing constant. Consequently, current survey staffs are aging and not training or mentoring their eventual replacements. The MGS has not hired a new geologist for its staff in over 15 years and yet the 13 MGS staff involved with some aspect of geologic mapping range in age from the mid-40s to the early 60s. The USGS has effectively had a freeze on new hires for the better part of three decades. So while there is an acknowledged need for continued geologic mapping, a crisis is clearly looming over the next ten years as the current groups of survey-based geologic mappers retire. In addition to the retirement issues geologic surveys are having real difficulties in recruiting and retaining their geological staffs because they cannot compete with the salaries being offered to geologists by the minerals industry. The PRC plans to utilize the outstanding skills of the experienced MGS staff to realize its vision of developing an organization that trains young geoscientists in geological field mapping could be a vehicle to fill future staffing needs of geological surveys. As well,

the PRC sponsored geological mapping and research will add much to our understanding of many Precambrian geoscience questions that are today unanswered.

#### **2.4 *University of Minnesota Duluth (UMD)***

The University of Minnesota Duluth is perhaps uniquely situated among U.S. universities to address the dwindling supply of geology students adequately trained in geological mapping of Precambrian rocks. It is situated just south of the juncture of three Precambrian terrains (Figs. 7 & 8) and is one of the few geology departments in the upper Midwest that still has an economic geology program. Moreover, UMD has a long-standing reputation for producing versatile, field-savvy students at the bachelors, masters, and doctoral levels familiar with the Precambrian geology of the Lake Superior region. This well-deserved reputation was built over a period of 50 years by a faculty of outstanding field geologists - including Heller, Lepp, Marsden, Davidson, Green, Matsch, Ojakangas, Morton(s) and Grant - who, to a person, took an interest in the geology in their backyard and passed that knowledge on to hundreds of geology students. While other departments in the U.S. could claim their students were well-trained in various aspects of field geology, particularly Rocky Mountain geology, UMD was renowned within U.S. academic circles for specializing in field studies of the unique aspects of glaciated terrains of the Canadian Shield.

The PRC's goal of developing a high quality and productive program that impacts basic and applied aspects of the geological sciences in fundamental ways is in keeping with the land grant mission of the University of Minnesota. We know of no such program concentrating on Precambrian rocks and geological mapping in any university geoscience department in the U.S., which makes the PRC unique to all peer institutions of the University of Minnesota. The PRC will facilitate intellectual synergies within the University of Minnesota system, as well as strong collaborations with geoscientists from industry, academia, and agencies outside of the university. President Bruininks' Strategic Positioning Initiative intends to have the University of Minnesota be ranked among the top three public research universities in the world. Such an initiative requires that all members of the university do their part in education, research, and developing associated collaborations to see that initiative comes to fruition. The PRC will, in the arena of the geosciences, substantially add to this initiative by developing an innovative geoscience program which incorporates teaching, research, and industry partnerships. As well, the PRC will foster strong relationships between geological research scientists at the NRRI, the Minnesota Geological Survey, faculty and students in the UMD Department of Geological Sciences, and professional geologists and students from throughout North America. The PRC will strongly assist the UMD Department of Geological Sciences in its mission to be recognized nationally for quality of undergraduate and graduate education and research (to be a top-25 M.S. geoscience program).

#### **2.5 *State of Minnesota***

Unlike mineral industry companies or geology students, the state cannot move outside its borders to seek better opportunities, and therefore must do what it can, in ways that it can, to attract new business opportunities. The PRC would play an important role in sustaining and expanding the state's economy through its geoscience endeavors in many direct and indirect ways. Directly, the PRC will provide the state and the industries working within the state with a pool of well-trained geoscientists or with continuing educational opportunities for their current staffs. Another direct benefit is that the PRC's research would greatly expand and disseminate our knowledge of the region's geology and mineral potential. Indirectly, the presence of the PRC will benefit the state by developing strong partnerships and collaborations with established mineral industries (taconite and perhaps soon, Cu-Ni-PGE mining) and with companies looking to explore for mineral resources in Minnesota. One means of collaboration is to develop sponsorships of graduate research on industry generated projects that will benefit both the industry and the student. Another type of collaboration is the offering of workshops and field experiences

on topics that will bring together geologists from the public agencies, academia, and local and regional minerals industries. Although the overall attractiveness of the state to the minerals industry is a function of many factors beyond the realm of the PRC's mission, i.e., taxation, mining royalties, environmental regulations, and infrastructure, the role of the PRC as a source of field-based geologic information and human resources should surely help make Minnesota an attractive place to do business for the minerals industry. This will benefit all citizens of the state with increase tax revenues and with well-paying jobs.

On top of the increased global need for trained field geologists, a more local need exists for the next generation of industry-based Precambrian geologists in Minnesota. The single most important need exists within companies mining taconite along the Mesabi Iron Range, which together contribute nearly \$1.3 billion to the state's economy every year in the form of purchases, wages and benefits, and taxes and royalties. It is imperative that these established mining facilities have access to the next generation of geologists for their staffs (a large percentage are UMD graduates). Also, UMD graduate student research projects on a variety of topics within the Biwabik Iron Formation could play an important role in sustaining existing mines and planned expansions into the future. A second state need is looming as Minnesota is poised to develop a wholly new mining district focused on Cu-Ni-PGE deposits of the basal Duluth Complex. PolyMet Mining Corporation is in the final stages of permitting to mine the NorthMet deposit located near Hoyt Lakes. Other related deposits have also seen increased activity in recent years, Teck-Cominco's Babbitt deposit, Franconia Mineral's Birch Lake and Maturi deposits, and Wallbridge America's Maturi Extension deposit. The potential exists that if PolyMet is successful in permitting and developing a base and precious metal mine, these other deposits are sure to follow. This will generate an incredible local demand for field-trained geologist with B.S. and M.S. degrees. Besides the Cu-Ni-PGE deposits of the Duluth Complex, other companies are spending money in the state in their search for gold, nickel, titanium, and diamonds.

### **3. PROGRAM COMPONENTS**

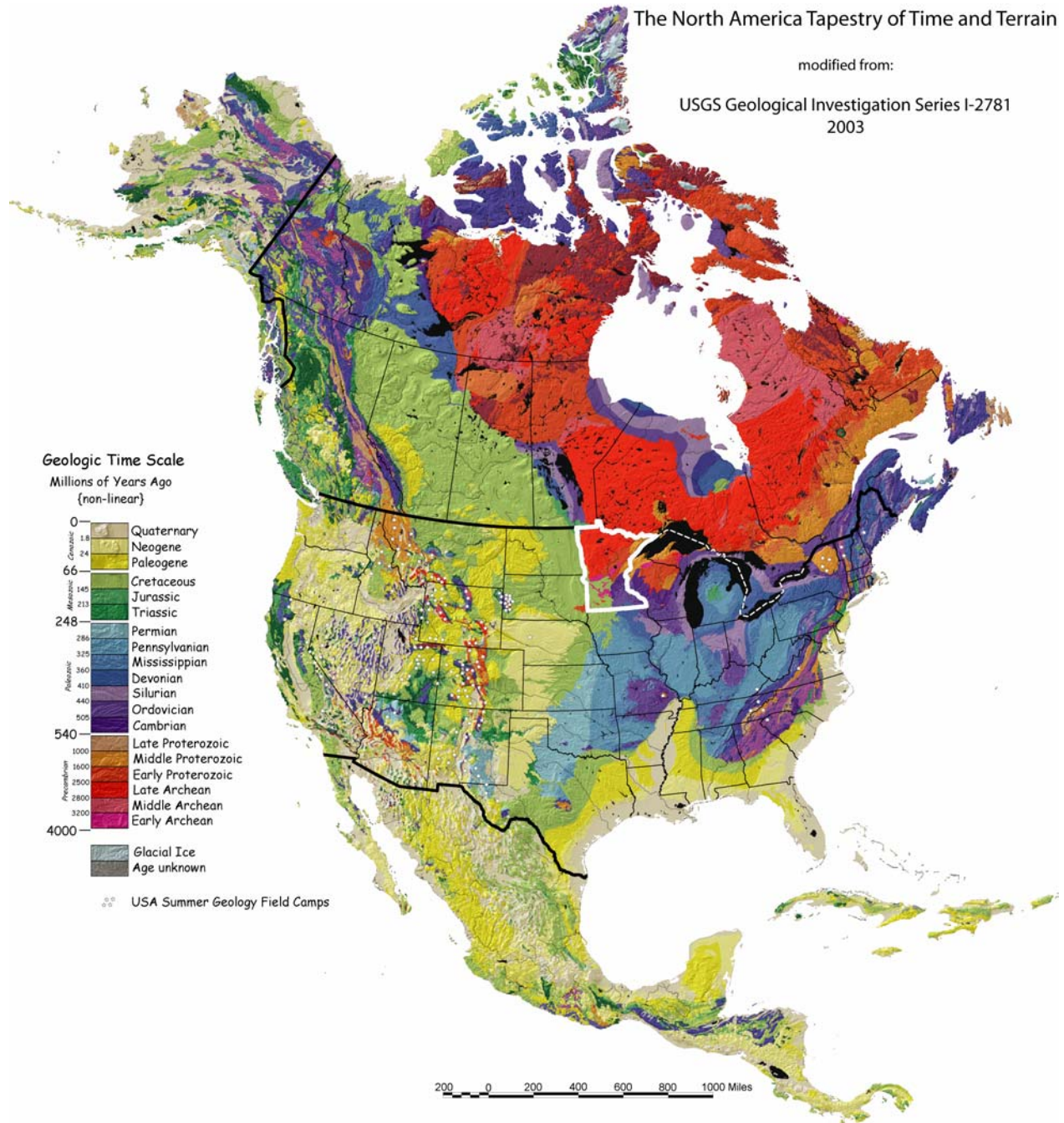
The PRC will accomplish its goals of training and supporting geoscientist in methods of field mapping, of attracting graduate students to UMD's graduate program, and of assisting students with finding employment with five main programs: (1) summer geology field camp in northeastern Minnesota; (2) research assistantships and grant for field-oriented research at UMD; (3) professional workshops and field experiences on particular aspects of Precambrian field studies and geologic map-making; (4) upper-level course offerings at UMD on field methods and digital geologic map-making; and (5) outreach, mentoring and career counseling. It is imperative that the PRC develop a plan that enables it to start, grow, and sustain itself into the future. The PRC's proposed program components are presented in the following sections of this document.

#### **3.1 *Summer Field Camp***

Most colleges and universities in the U.S. require undergraduate geology students to attend a summer field camp, which typically is the students' capstone course that integrates their undergraduate geology education into making geologic maps and acquiring field skills necessary to practice geology. Of the 151 identified localities where U.S. colleges and universities teach these courses, 136 are in the Rocky Mountains and 13 are in the Appalachian Mountains (Fig. 6).

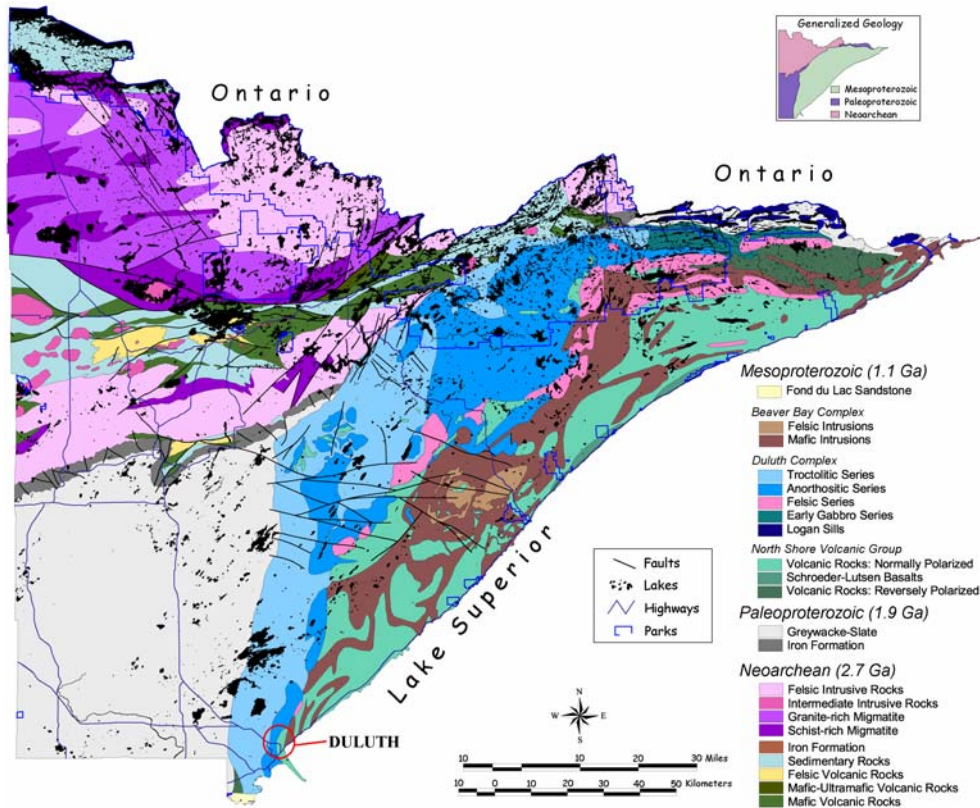
For the most part, these camps teach field geology well, although the camps are generally limited to mountainous exposures of Phanerozoic (the Paleozoic, Mesozoic, and Cenozoic eras) rocks. However, some field camps are little more than extended field tours visiting national parks and classic geologic overlooks of the Southwest, with little or no actual field activities. Overall, the rocks mapped in these field camps span only the last 540 million years of geologic time (a mere 12% of Earth history), with individual field camps commonly completing the majority of their field projects in a much more restricted

span of Earth history. The typical field camp course involves completing a geological map and 2-D cross section from a number of mapping areas, with student grades based upon the comparison of their work to map keys, i.e. the field camp's interpretation of the geology of the area. The individuals teaching in these field camps are almost exclusively professors of geological science at host academic institutions, which vary from individuals with exceptional field skills to professors that have limited field mapping experience.



**Figure 6.** Map showing the bedrock geology age draped on a digital terrain map, modified from the USGS Geological Investigation Series report I-2781. Small white stars show the approximate field location of the 151 identified geological field camps hosted by U.S. colleges and universities.

The PRC intends to develop a new summer field camp course based in the Precambrian terrains of northern Minnesota (Fig. 7) through the auspices of the Department of Geological Sciences at UMD. This camp will be designed to meet undergraduate requirements of most university and college geology programs, and will be an open enrollment course to students from the U.S., Canada, and abroad. The course will be based in a number of locations throughout northern Minnesota, including Duluth, Hibbing, Ely, campsites within the Boundary Waters Canoe Area Wilderness (BWCAW), and other remote sites. The educational goals of the camp will parallel those of traditional summer field geology camps in terms of developing basic field-geology skills. However, PRC-run field courses will provide students with the added opportunity to conduct independent and group geological mapping in canoe-access wilderness areas (BWCAW) where our current knowledge of the geology is based on reconnaissance mapping in the 1930s. A long-term goal of PRC-led field courses is to compile student geologic mapping for eventual publication, thereby contributing to the scientific record in the region.



**Figure 7.** Simplified bedrock geology map of northeastern Minnesota.

The educational goals of the field camp include teaching:

- the fundamentals and basics of bedrock and surficial geologic mapping methods
- development of observational, data collection, analysis, and interpretation skills
- critical thinking skills
- hypothesis testing, development and analysis of multiple working hypotheses
- the concept of uncertainty in the analysis and interpretation of geologic data
- the appreciation of scale in both field mapping and as applied to geologic phenomena
- 4-dimensional reasoning
- recognition of the "footprint" of various geological phenomena
- introduction to drill core logging and 3D interpretation of geological data
- integration and interpretation of geophysical data into mapping projects

- introduction to professional-quality digital map generation using geographic information systems

The PRC field camp differs from traditional geological field camps in a number of ways. First and foremost is that the camp will include bedrock geologic mapping projects exclusively in Precambrian rocks of the Canadian Shield in northern Minnesota. The mapping projects will include rocks that span 38% of Earth history (2.72 – 1.09 billion years ago) that have essentially been eroded over eons into a low relief surface. Such rocks form the core of all continents (see Fig. 6) and are extremely important in that they host a large proportion of mineral deposits utilized by society today.

Secondly, the PRC field camp will largely be taught by experienced field geologists from the Minnesota Geological Survey and NRRI (along with university faculty) whose main occupations are researching Minnesota's geology and publishing geological maps. Such geologists understand that the relative quality of any geological map (including the student's) is a function of many factors, including: the frequency and distribution of outcrops; the complexity of stratigraphy and structure; the nature of topography; the experience of the field geologist; and the quality and quantity of previous investigations. These experienced geoscientists have a true passion for field geology, and are willing and able to pass on their accumulated knowledge to students enrolled in the camp.

Lastly, the PRC field camp will include a variety of intensive small group (5 to 7 students) wilderness field mapping experiences in the BWCAW or adjacent areas with a single field camp faculty member in essentially unexplored terrains. These capstone field projects provide the student with the real opportunity of working with a professional field geologist as the group determines the geology of their project area. In addition, such an experience gives the student a sense of ownership of the final map, which over time, will ideally result in the publication of a series of 1:24,000 scale geological quadrangle maps (either Miscellaneous Map Series (M-series) MGS or Investigation Series (I-series) USGS maps). There is no "key" for these culminating mapping projects because such data does not exist, and the students will experience the "discovery of new data and geologic insight" that routinely occur in the careers of professional field geologists. The camp will culminate in the integration of the small group field mapping data into digital datasets that meet the standards of the MGS and USGS, and thus form the framework for eventual publication. A preliminary outline for a six-week (and a three-week option) Precambrian field camp is outlined below, and a preliminary listing of bedrock mapping projects ideas that can be incorporated into the Precambrian field camp are given in Appendix 2.

- Week #1** - *Overview of the Precambrian geology of northeastern Minnesota*  
- *Field trips to the Vermilion District, Mesabi Range, Duluth Complex, North Shore, central Minnesota, Minnesota River Valley*  
- *Introduction to field methods in glaciated Precambrian terrains*
- Week #2** - *Bedrock mapping projects*  
- *Ground geophysics project (1-day, gravity and magnetics)*
- Week #3** - *Bedrock mapping projects*  
- *Quaternary geology mapping project*  
- *Drill core logging project*
- Week #4** - *Bedrock mapping projects*
- Week #5** - *Capstone mapping project (choice of 4-5 project areas, wilderness options, field parties consisting of 5-7 students and one instructor)*
- Week #6** - *Digital compilation of capstone project field data and geologic map-making; presentations*

### **3.2 *Research Assistantships and Grants***

One of the fundamental goals of the PRC is to attract outstanding students to UMD's geology graduate program by making research assistantships available for support of theses and dissertation topics on various aspects of Precambrian geology of Minnesota and the greater Lake Superior region. Four research assistantships of approximately \$31,680 each per year (12-month salary \$15,860; health insurance \$2,320; research money \$4,820; tuition waiver \$8,681) will be offered annually for graduate student research. Two research assistantships are projected to be funded in the fall of 2007, and four beginning in the fall of 2008. Students seeking M.S. degrees will typically be offered up to two years of support and Ph.D. students may receive up to four years of support. Funding for graduate student research assistantships will be generated through the PRC, but students will be expected to apply for additional research funding from other sources, i.e., Society of Economic Geologists, Geological Society of America.

The PRC will solicit research proposals from prospective graduate students or will allow students to select from a pre-generated list of research topics that will potentially be funded by the center (see Appendix 1). This list will be developed in consultation with geological surveys (MGS, USGS, OGS, MGS (Manitoba)), academic institutions from throughout the Midwest, and the minerals industry. The PRC's goal is to cumulatively build these projects into a framework of advanced knowledge on many aspects of the Precambrian geology of the Lake Superior area.

Funding undergraduate student field-based research projects on topics in Precambrian geology will be a key component in the PRC's mission, and is envisioned to be a vehicle in steering students towards careers in geological mapping, Precambrian geology, and the minerals industry. The PRC intends to allocate approximately \$25,000 per year to fund a number of undergraduate student research projects. Students soliciting these funds can be from any accredited geoscience department in the U.S. or Canada in the Lake Superior area as long as they have strong support from a faculty member of their host geoscience department. To obtain funding, undergraduate students will submit a two-page proposal to the PRC's directors outlining their research objectives, describing their research activities, and listing their expected accomplishments. Funded students will be strongly encouraged to present their findings at the annual Institute on Lake Superior Geology (ILSG) meeting.

### **3.3 *Professional Workshops and Field Experiences***

The PRC's goal of advanced training and/or retraining of professional geologists (and geology students) will be achieved through the development of a series of workshops/shortcourses on topics important to geological mapping, Precambrian geology, and the minerals industry. In addition, specialized geological mapping experiences for groups of industry geologists and/or the geological staff of individual companies will be arranged as warranted. These individualized mapping experiences could play an important role in developing the intellectual capital of these companies as well as introducing Minnesota's geology to the minerals industry. The PRC will work closely with Department of Continuing Education at UMD to ensure that these professional development programs meet the Continuing Professional Development requirements (credits, hours) of geological licensing boards. A preliminary listing of workshop/shortcourse topics and geological mapping experiences are listed below:

#### ***Workshop/Shortcourse Topics***

- Using Geographical Information Systems (GIS) in geological mapping
- Using GIS spatial analysis as a tool in mineral exploration
- Integrating geophysical data in bedrock geologic mapping
- Using surficial geology as guides to bedrock mapping

- Recognition of mineralization indicators from field observations
- Integrating detailed structural mapping into subsurface interpretations
- Using geochemistry and petrography in bedrock mapping
- Techniques of drill core logging and subsurface interpretation
- 3D geological and geophysical mapping/modeling
- Introduction to mineral processing for exploration geologists
- Geology of common Precambrian mineral deposits

### ***Geological Mapping Experiences***

- Geologic mapping of mafic intrusions within the Mesoproterozoic Duluth Complex: Identification of potential targets for Cu-Ni-PGE, PGE reef, and titanium deposits.
- Geologic mapping in Archean granite-greenstone terranes: Identification of potential targets for lode-gold and volcanogenic massive sulfide (VMS) deposits.
- Geologic mapping from square one: Field experience in unmapped limited access/wilderness terranes as a proxy for future endeavors in the far north of Canada.
- Detailed geological mapping: Techniques of very detailed geological mapping of mineral prospects and/or company properties in North America.

### **3.4 Upper Level Geology Courses**

The staff and scientific collaborators of the PRC each have unique applied skills that have been honed through decades of professional work in geology. These applied skills are different than the research and teaching skills of the faculty members of the Department of Geological Sciences at UMD, and a program that integrates the applied skills of the PRC into the Geological Sciences curriculum at UMD will enhance the educational experience and careers of undergraduate and graduate students in the department. Four advanced geological science courses (upper level undergraduates and graduate students) will be taught in conjunction with the PRC, and involve instruction of methods and techniques commonly used by geologists in applied geoscience careers. These courses include: (a) Advanced Field Methods and Geological Maps; (b) Geology in Three-Dimensions; (c) Geologic Problem Solving using Digital Methods, and (d) Special Topics seminar courses.

#### ***Advanced Field Methods and Geological Maps***

GEOL 5XXX (4.0 cr; Grad school student, or instructor consent; A-F, fall)

Advanced techniques in field mapping and digital map preparation: geological and structural mapping, integration of geophysics and geochemistry into geological maps, GIS database generation, projection systems and cartographic conventions, and structural and stratigraphic compatibility of geological maps.

#### ***Geology in Three-Dimensions***

GEOL 5XXX (2.0 cr; Grad school student, or instructor consent; A-F, J-term)

Introduction to three-dimensional geological mapping and modeling using state-of-the-art geological (gOcad) and geophysical inversion (MAG3D & GRAV3D) computer software. Graduate students enrolled in the course will use their individual thesis topic geological data in the course.

#### ***Geologic Problem Solving using Digital Methods***

GEOL 5XXX (1.0 cr; Prereq-Jr or Sr or grad student in Geol, or instructor consent; A-F, spring)

Overview of the common types of digital geological data (points, lines, surfaces, volumes). The course will teach common techniques used by geoscientists that manipulate these data into useful information (maps, tables, images, graphs, visualizations) to answer specific questions.

***Special Topics (Various Topics on Precambrian Geology)***

GEOL 5095 (1.0 - 2.0 cr [max 4.0 cr]; Prereq-#: A-F or Aud, fall, spring, every year)

Geology seminar course on topics related to the Precambrian geology of the Upper Midwest and Northwestern Ontario and mineral deposit types hosted by Precambrian rocks.

**3.5 *Other Education, Outreach, Mentoring and Career Planning***

Universities should be places that introduce students to different ideas, different people, different institutions, and different career possibilities. The PRC's vision in collaborating with students and geoscience faculty from academic institutions throughout the Lake Superior region is two-fold: (1) leading and sponsoring Precambrian geology field trips for individual geology classes from neighboring institutions and/or multiple classes from groups of geology departments in the region, and (2) funding Precambrian geology research projects (~\$25,000 per year) for undergraduate students from UMD and these other academic geoscience departments (see Section 3.2). The PRC feels that inter-institutional partnerships, programs, and activities will foster a culture in which geological mapping and Precambrian geology can flourish.

Outreach to the public will be facilitated by the PRC through volunteering to give presentations at public meetings and within the K-12 schools in the region. As well, the PRC intends to build relationships with local community leaders, especially within the Iron Range region of northern Minnesota, and help these communities plan for the future (in conjunction with the possible opening of major new copper-nickel mines). The PRC directors and many of its collaborators are highly-skilled professional geologists outside of the tenure-track realm of academia. As such, these individuals are perfect candidates for the role of mentors to all of the students that interact with the PRC, including those at UMD and those outside of UMD. In addition, the students have much to give back to these mentors, especially by asking thought provoking questions on geologic phenomena. Such questions are the basis upon which the sciences advance to new heights.

The PRC will have direct access to a number of individuals, organizations, academic institutions, and companies that employ and/or educate geologists. These relationships, as well as those developed with PRC associated students; bode well for counseling students along career paths and matching employers with qualified students.

**4. BUSINESS MODEL**

The core of the business model for the PRC is based on the proposition that the center serves five benefactors or customers (as described in section 2) with service products (as described in Section 3) that are of high value and quality and are greatly needed by the geosciences community. However, critical to the success of the PRC is the need to develop an organizational structure, a core of benefactors, a quality marketing plan and a robust budget plan that will sustain it over the long term. These business components are considered below.

**4.1 *Organizational Structure***

Although the PRC will involve many public and private partners, at its core, it will be a collaboration among various staff members of three University of Minnesota institutions: the Department of Geological Sciences at UMD, the Natural Resources Research Institute (NRRI) at UMD, and the Minnesota Geological Survey (MGS) of the University of Minnesota Twin Cities campus. These three University of Minnesota institutions are uniquely positioned to collectively satisfy the new and sustained demand for

field-experienced geoscientists. Over the past five decades, the geology department at UMD has established a global reputation for producing field-trained geologists, particularly familiar with Precambrian geology. Field savvy UMD geology graduates populate many of the major exploration companies, academic institutions, and geologic surveys, commonly in disproportionate number. The mission of the NRRI also fits objectives of the PRC with its mission to promote sustainable development of Minnesota's natural resources in an environmentally responsible manner that leads to private sector employment. The NRRI's efforts cover an array of activities in economic geology that focus on collaboration with the public sector and private industry. The MGS has as its main charter, the task of compiling and disseminating regional geologic information about the state to industry, state government, and the general public.

The manner by which these three organizations will share oversight of the PRC is portrayed in the organizational chart presented in Figure 8. The PRC is envisioned to be a research institute within UMD falling under the guidance of both the Center for Applied Research and Technology Development (CARTD) at the NRRI (Don Fosnacht, director) and the Department of Geological Sciences in the College of Science and Engineering (Penny Morton, department chair). The business and financial elements of the PRC will be assisted by CARTD-NRRI, whereas educational and student support elements will be assisted by the geology department. The MGS's role will not be managerial, but rather will provide: (1) counsel about Precambrian areas within the state in need of geologic mapping (critical to EDMAP funding), (2) staff to assist in PRC programs and mentor/advise PRC-sponsored students, and (3) publication and editing resources by which to disseminate PRC-generated maps and reports. All of these supervisory organizations will have a permanent seat on the Board of Advisors that will be filled by the department heads/directors or their proxies.

Initially, it is envisioned that the PRC will have three permanent, but part-time employees who will draw part of their University salaries from PRC funds. These are the two proposed PRC directors, Dean M. Peterson (NRRI) and James D. Miller (MGS) and an accounting manager yet to be identified (though probably Denise Endicott). The co-directors are both employed by the University of Minnesota and have adjunct faculty positions with graduate advisor status in the Department of Geological Sciences at UMD. Brief vitas for Drs. Peterson and Miller are given in Appendix 4. Both Peterson and Miller will retain their full-time affiliation with their host University of Minnesota departments (NRRI-Peterson, MGS-Miller) and will continue to receive salaries determined by their host departments. The NRRI and MGS would be compensated from the PRC for salary and fringe benefits concomitant with the level of effort that Peterson and Miller devoted to PRC business, which could range from 3 to 6 months per year each. Ideally, the accounting manager would be someone familiar with the business workings of the University and might therefore come from the University's civil service ranks, probably from within the NRRI. The annual level of effort by the accounting manager would also probably range between 2 to 3 months and would be paid out of PRC funds.

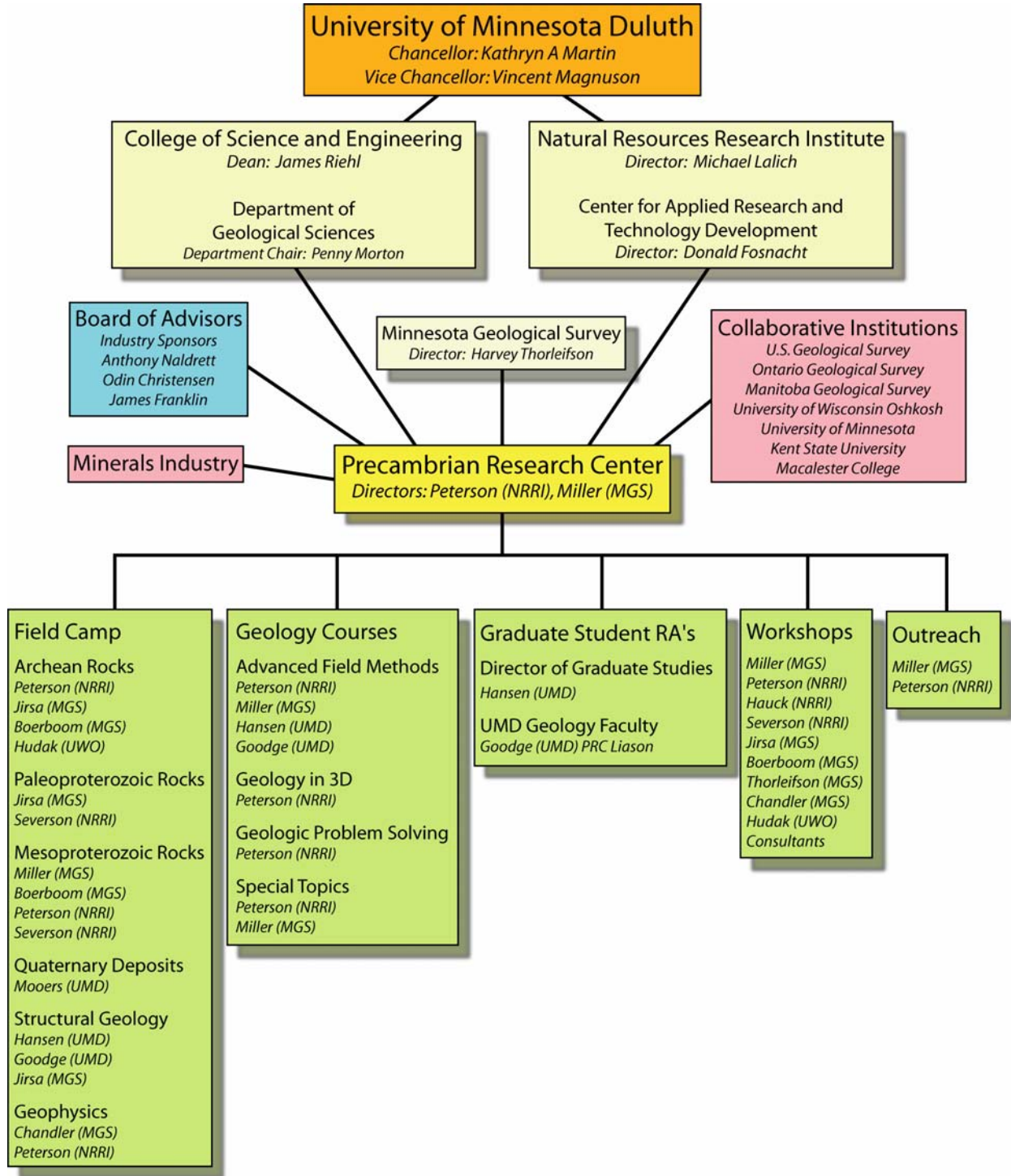


Figure 8. Organizational structure of the PRC.

**4.1.1 Intellectual Capital** - The intellectual capital of the PRC will stem mainly from the many professional and academic collaborators who will be contracted for the various program components. An initial listing of field-experienced geoscientists and their host institutions from the Lake Superior region, who have expressed interest in being involved in PRC activities include:

UMD Department of Geological Sciences - Vicki Hansen, John Goodge, Howard Mooers, Ron Morton, Penny Morton, Tim Demko, Christina Gallup, Nigel Wattus

NRRI – Dean Peterson, Steven Hauck, Mark Severson, John Heine

MGS – Jim Miller, Harvey Thorleifson, Mark Jirsa, Terry Boerboom, Val Chandler

U.S. Geological Survey - Randall Orndorff, Klaus Schulz, Laurel Woodruff, William Cannon

Manitoba Geological Survey - Alan Bailes, Rick Syme

Ontario Geological Survey – Gregg Stott, Mark Smyk

University of Minnesota Twin Cities – Calvin Alexander, Paul Morin

University of Wisconsin-Oshkosh – George Hudak

Kent State University – Daniel Holm

Macalester College – Karl Wirth

The geological collaborators and staff of the PRC collectively have over 600 years of professional experience focused largely on field studies in Precambrian terrains, and have together published hundreds of geological maps, manuscripts, and reports (both public and confidential) in the scientific literature. Most of these field-based geoscientists are currently in the prime stages of their careers, and have the experience, health, and desire to pass on this broad base of knowledge on geological mapping and Precambrian geology to the next generation of geologists.

In addition, outstanding geologists from numerous mining and mineral exploration companies have also indicated their support for the PRC's mission, and many are willing and able to assist in its education and research programs. These collaborators will be contracted for time and expenses for their involvement with PRC activities, particularly summer field camp and professional workshops. This support will typically come in the form of stipends, but may involve contracts for those within the University of Minnesota system.

**4.1.2 Board of Advisors** - A Board of Advisors will be organized to offer advice and counsel on PRC programs. The Board will serve as a vehicle for communication and interaction between the PRC, academia, geological surveys, and the mineral industry and will be composed of at least 10 chairs. Two of these will be filled by the heads of the PRC's supervising institutions (CARTD-NRRI and Department of Geological Sciences) or their appointees. Three chairs will be filled by representatives from the Minnesota Geological Survey (its Director), the U.S. Geological Survey, and a Canadian survey (Canadian Geological Survey, Ontario Geological Survey or Manitoba Geological Survey). Three chairs will be filled by leading academics that are renowned for their field-based research of Precambrian rocks. The final chairs will be filled by the directors of the PRC. Two chairs will be filled by prominent geologists selected from the minerals industry. Additional chairs will be created to accommodate industry members who have contributed to the PRC at the Platinum membership level or above (see Section 4.2). In addition to being ambassadors for the PRC in the larger geological community, the board will provide fresh and objective viewpoints to the PRC on strategy, curriculum, funding opportunities, and research programs. Board members may also engage our students as co-op employers, mentors and guest speakers.

Three preeminent geoscientists have agreed to join, and form the initial core of the PRC Board of Advisors: Dr. James Franklin (formerly Chief Scientist, Geological Survey of Canada), Dr. Anthony Naldrett (Emeritus Professor of Economic Geology, University of Toronto), and Dr. Odin Christensen (former Chief Geologist, Newmont Mining Corporation). Biographical sketches of each of these individuals are given in Appendix 4.

The Board will meet annually, perhaps in conjunction with the Institute on Lake Superior Geology meetings in May or perhaps in July or August to allow the board members to observe and participate in the summer field camp. A budget of \$10,000 per year has been set aside to pay expenses for these board meetings. The directors will compile an annual report of PRC activities and finances that will be distributed to the Board a month before each annual meeting.

#### 4.2 Benefactors

Financial resources are required to start, build, and sustain the PRC into the future. Preliminary projections of the PRC budget, which includes income and expenditures, are given in Section 4.4. These projections indicate that by 2008, when all of the expected program components of the PRC are operational, the PRC budget will be approximately \$488,000 per year. To ensure that the PRC’s vision is realized and its goals are met, it is expected that the beneficiaries of the PRC, i.e. its five customers, will be the primary benefactors for the center. Our success in fund raising will depend largely on the extent to which we can convince potential contributors that the benefits the PRC will provide will greatly exceed their financial commitments and then follow through on that promise.

Simple breakdowns of the projected funds that each of the PRC customer is expected to invest by the year 2008 (and is approximately the expected annual budget for subsequent years) are:

- \$106,000 – Geology Students
- \$115,000 – Minerals Industry
- \$30,000 – Geological Surveys
- \$187,000 – University of Minnesota
- \$50,000 – State of Minnesota

**4.2.1 Students** - Geology students will “invest” in the PRC through the tuition and fees they will pay for summer field camp, PRC-sponsored courses at UMD, and workshops. The average cost (tuition, fees, room and board) for an undergraduate geology student in the U.S. to complete a six-week geology field camp is approximately \$3,000 (Fig. 9). A preliminary estimate of the cost per student for the PRC field camp in 2008 is \$2,650, which would bring in \$106,000 in income (if forty students are enrolled) to the PRC (less UMD administrative cost) to run the field camp.

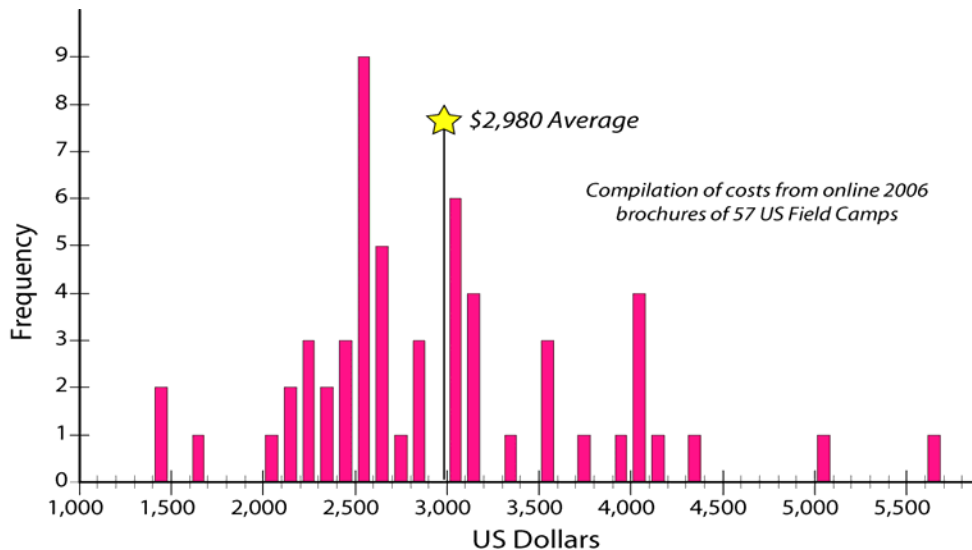


Figure 9. Histogram of total costs (tuition, fees, room and board) for students to attend geology field camp.

**4.2.2 Industry** - An important task of the directors of the PRC will be fund-raising among professional geologists and minerals exploration and mining companies. The PRC intends to seek a substantial investment from the minerals industry in three ways: industry memberships, sponsorship of industry-generated research projects, and workshop/field experience fees. Preliminary projections of potential industry funding of the PRC are presented in Section 5 of this document. These projections total \$115,000 by 2008, and include \$50,000 in memberships, \$35,000 in sponsored research projects, and \$30,000 in workshop fees.

Industry Memberships - In order to give the mineral industry a sense of ownership in the PRC, we intend to solicit partial funding of the center through a variety of membership levels as listed in the table below. Industry members (which could also include governmental agencies) will have direct access to the PRC's directors and will be encouraged to discuss geological staffing and research needs of their organizations. Such discussions will form an important component of the PRC's student career planning and job placement activities (see Section 3.5), and will ideally lead to employment of PRC students into these organizations. All members will receive the annual PRC newsletter and the annual report, and will have access to non-confidential research underway within the PRC. Memberships above the corresponding level, will receive 20-50% reduction in registration fees charged for semi-regular professional workshops and field experiences. Gold members and above will be given free advertising in the PRC newsletter. Diamond and Platinum corporate members will be given a position on the Board of Advisors (Diamond 2 positions, Platinum 1 position), and thus will have a strong voice in influencing the direction and emphasis of PRC education and research programs. These members will have the opportunity to meet the geology students enrolled in the summer field camp, and will be encouraged to give short presentations about their organization to the field camp. A preliminary budget estimates that, by 2008, industry memberships will be expected to generate \$50,000. From the preliminary responses we have received from the minerals industry, we believe that is a minimum estimate – there is a strong probability of increasing these projections. The costs of memberships given in the table below are modeled after similar public-private partnerships of mineral exploration research centers (see Section 6).

<b>Membership Level</b>	<b>Annual Cost</b>	<b>Fee Reduction</b>	<b>Newsletter Advertising</b>	<b>Board of Advisors</b>
Diamond	\$30,000	50%	X	X X
Platinum	\$15,000	33%	X	X
Gold	\$7,500	25%	X	
Copper (corporate)	\$2,500	20%	X	
Titanium (individual)	\$500	20%		
Aluminum (corresponding)	\$200	-		

Another second way that industry can support the PRC is to fund students and PRC staff to conduct research on industry-generated projects. This type of support is envisioned to fall into two categories: (1) full or partial support to M.S. and Ph.D. graduate students for dissertation research on projects of interest to a particular company; and (2) funding to PRC staff for research projects that will involve geology students from UMD and/or PRC affiliated academic institutions. Industry-sponsored research projects are one of the cornerstones of research funds that geoscientists at the NRRI currently use to unravel the geology and mineral potential of northeastern Minnesota rocks. These projects have fostered strong ties between the NRRI and the local mineral industry, which will be enhanced by the PRC by involving numerous undergraduate and graduate geology students in the future. Support levels for sponsorships of industry-generated projects are targeted to be \$35,000.

Finally, industry support of the PRC will come in the form of registration fees paid for the biannual workshops and field experiences. Registration fees will be structured to cover actual costs of the various

programs, plus a 20% additional fee that will go towards the PRC's general operating fund. With industry members receiving registration fee reduction of 20-50%, this additional fee will not be realized for gold, platinum, or diamond members, but will result some of their membership contribution going toward their registration.

**4.2.3 Geological Surveys** - Funding into the PRC by geological surveys is difficult to project. We believe that there are three possible routes in which the PRC can generate "income" from these governmental agencies: (1) salary and fringe benefit cost sharing between the PRC and associated state or provincial geological survey for utilizing their professional staff in PRC activities; (2) actively pursue grants and partnerships with the U.S. Geological Survey (as outlined in the 2004 National Academy of Sciences report "*Future Challenges for the U.S. Geological Survey's Mineral Resources Program*"); and (3) partial funding of geological mapping by UMD students through the U.S. Geological Survey's EDMAP and STATEMAP programs (see Section 2.3). The preliminary budget (see Section 5) includes \$30,000 of "income" from geological surveys in the form of EDMAP grants in support of graduate student mapping.

**4.2.4 University of Minnesota Duluth** – The PRC's goal of developing a "center of excellence" in geological mapping will serve to retain and enhance UMD's reputation in this most fundamental of geoscience endeavors. It is believed that the PRC concept falls well within the scope of President Bruininks' Strategic Positioning Initiative for the entire University of Minnesota system, and thus deserves strong support from many levels from within the university. Therefore, the PRC intends to seek much of its base-level funding from the university, including: (1) approximately \$100,000 per year from the NRRI from the Mineral Research Account of the Permanent University Trust Fund (PUFT); (2) tuition waivers for four PRC-funded graduate student research assistantships (~\$35,000 per year); (3) in-state tuition for out-of-state students enrolled in the field camp; (4) allowing for a large percentage (90%) of the field camp tuition payments be used by the PRC to pay salaries of field camp faculty (~\$52,000 per year) – similar to the current arrangement with UMD Geology and the Wasatch-Uinta Field Camp; and (5) finding and remodeling office space for the PRC in Heller Hall. In addition, the faculty of the Department of Geological Sciences at UMD recognizes the role that the PRC could play in their mission, and on their own have internally proposed that two new tenure-track faculty positions be awarded to the department to assist the PRC on its mission.

**4.2.5 State of Minnesota** - The State of Minnesota may well be the largest beneficiary of "proceeds" from a fully operational PRC as discussed in section 2.5. The PRC will seek funding from the state in two ways: (1) soliciting operating and research project funds from the Minerals Coordinating Committee, Iron Range Resources, and the Legislative Committee on Minnesota's Resources; and (2) solicit funding ideas to the State Legislature through the offices of Northeastern Minnesota State Representatives and State Senators. We have included \$40,000 under the heading PRC Research Grants in the 2008 budget that likely could be obtained from opportunities within the government of the State of Minnesota, as well as a \$10,000 grant from the state agency Iron Range Resources.

### **4.3 Marketing Strategy**

Successful marketing of the PRC's mission requires timely and relevant market information. An initial assessment of the demand for PRC programs is presented in Section 2 of this document. This information, together with personal communications with individuals throughout the geological community and the Letters of Support (Appendix 5) show the strong support for the PRC concept. To succeed, the PRC must develop a marketing strategy that addresses unmet needs of its five customers (geology students, the minerals industry, geological surveys, the University of Minnesota system, and the State of Minnesota) through the centers program components. The strategy will be revisited each year to assure that the PRC's performance of its geological initiatives is known throughout the geological

community and that the PRC attracts geology students, secures initial and continual funding, and attracts and retains mineral industry partners. The three components of this strategy include the PRC's: (1) products and services; (2) pricing; and (3) promotion.

The PRC's products and services are presented in Section 3 of this document. The pricing for these products and services (tuition fees for geology students, workshop fees for industry geoscientists, industry memberships) will typically be leveled at market prices, i.e., typical U.S. geology field camp costs and professional geological workshop fees. However, all attempts will be made to lower costs for geology students by developing the field camp endowment (to help defray costs for underprivileged students) and a commitment by UMD to charge in-state tuition for all students enrolled in the field camp. As well, the costs of paying adjunct faculty (Peterson and Miller) for teaching upper level geology courses will be covered by the PRC and not by the Department of Geological Sciences. The final component of the marketing plan includes the overall promotional objectives of the PRC: (1) to communicate the need in educating geoscientists in the science and art of geological mapping; (2) to create an awareness of the PRC in the geological community; and (3) to interest geology students, mineral industry partners, and geological funding agencies to be involved in the PRC's program. The promotion activities will include:

- Brochures and posters distributed to U.S. and Canadian colleges and universities advertising the summer field camp and the PRC's graduate research assistantships
- Advertisements in geological journals highlighting the PRC
- Publication of an annual report
- Publication of an annual PRC newsletter
- A dedicated web site
- Host a promotional booth at local, regional, and international geological meetings
- Publication of short articles and photographs from field camp in geological society magazines (we cannot imagine a better advertisement than a photograph of some of our field camp students on the shore of a BWCAW lake).
- Presentations of the PRC's vision and results at geological meetings and geoscience department seminars
- Publication of PRC sponsored research in peer reviewed journals
- If funding allows, the PRC will sponsored a Distinguished Speaker Lecture Series in which outstanding Precambrian geologists travel throughout the region (and farther) and give seminars on geological mapping, Precambrian geology, and the PRC.

#### **4.4 Budget Plan**

A three-year budget (calendar years 2006 – 2008) for all planned elements of the PRC is given in Table 1. This budget is preliminary and incorporates the projected income and associated PRC programmatic element expenditures. By 2008, the PRC is expected to generate approximately \$488,000 in income, and have expenditures of approximately \$402,000. As the authors of this budget are geologists and *not* University of Minnesota accountants, we are sure that there are many aspects of this budget that will need to be changed, though we have incorporated into the expenditures many obvious geological and educational elements. The bottom line is that the PRC nets a positive balance each of the three years incorporated into the budget. The mission of the PRC is reinvigorating the discipline of geological mapping of Precambrian rocks, especially focusing on training geology students to become outstanding field geologists. Therefore, the PRC intends to minimize costs for geology students, and will develop a field camp endowment (incorporating 50% of the positive annual balance) that will be used to help defray summer field camp costs for underprivileged students.

Two pie charts of budgetary elements are presented in Figure 10. In Chart A, the 2008 budget is broken down into programmatic elements and in Chart B into distribution elements. The two major budgetary components of the PRC program are the summer field camp and graduate student research assistantships, which together require nearly 47% of the PRC budget to complete. Administrative costs for the PRC are expected to be less than 11% of the budget. As can be expected, the single largest distribution of PRC income will be to pay salaries and fringe benefits (~\$139,000 per year) of professional geologists involved in PRC programs.

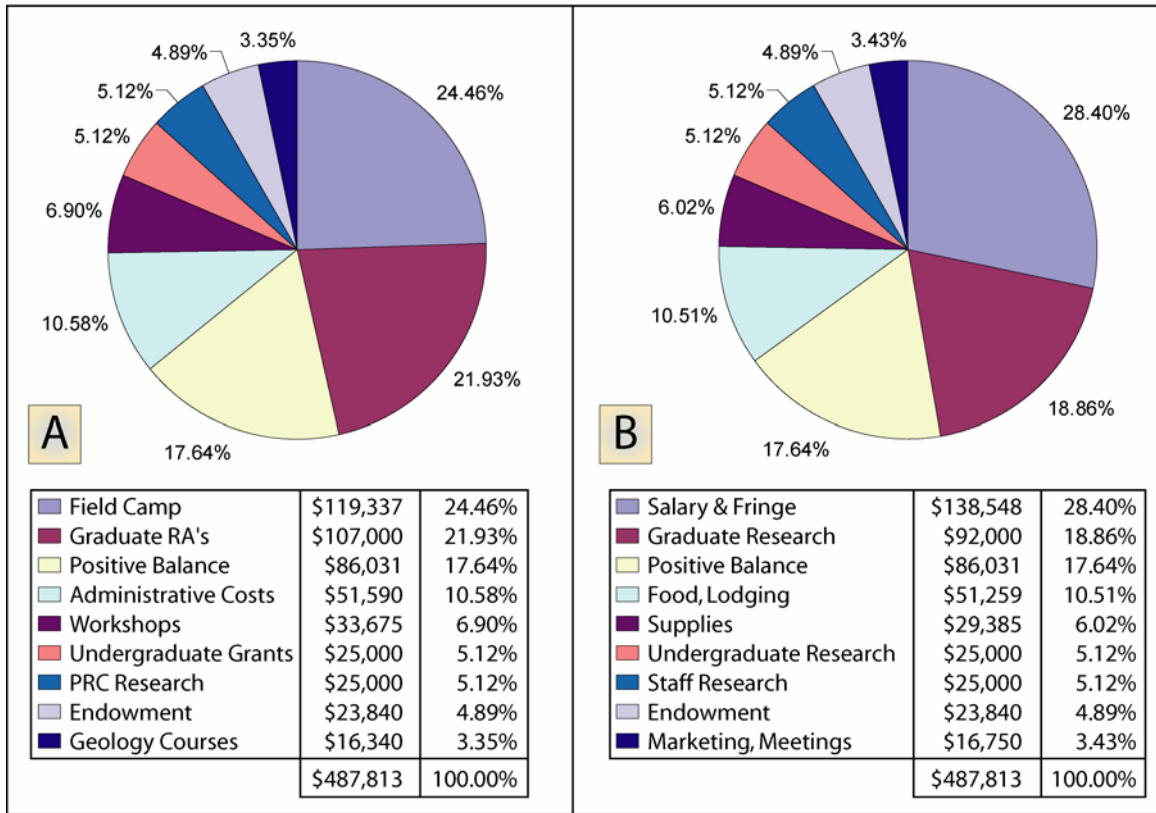


Fig. 10. Preliminary 2008 PRC budget based on costs of programmatic elements (A) and of budget categories (B).

As described above, half of the projected positive balance of PRC finances will be used to endow a field camp fund. The other half of this balance could be used for a number of purposes, which could include completing geochronology studies of Precambrian rocks in northern Minnesota, funding the Distinguished Lecture Series (see Section 4.3), hiring a young professional staff member into the PRC, sponsoring travel grants for geology students, or for additional support for public-private research programs (see Appendix 1).

Precambrian Research Center

Table 1. Preliminary budget for the Precambrian Research Center

<b>INCOME</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>
<i>Previous Year Carryover</i>	\$0	\$21,948	\$47,680
<i>PUFT Grant (University of Minnesota Trust)</i>	\$100,000	\$100,000	\$100,000
<i>CSE Graduate Student Funding</i>	\$0	\$17,500	\$35,000
<i>USGS (EDMAP Grants)</i>	\$0	\$15,000	\$30,000
<i>Iron Range Resources Grant</i>	\$5,000	\$10,000	\$10,000
<i>Private Foundations</i>	\$0	\$5,000	\$10,000
<i>Industry Sponsorships</i>	\$10,000	\$30,000	\$50,000
<i>Industry Research Grants</i>	\$10,000	\$25,000	\$35,000
<i>Field Camp Fees</i>	\$0	\$71,571	\$100,133
<i>Workshop Fees</i>	\$10,000	\$20,000	\$30,000
<i>Public Research Grants (NSF, USGS, MCC)</i>	\$0	\$20,000	\$40,000
<b>SUBTOTAL:</b>	<b>\$135,000</b>	<b>\$336,019</b>	<b>\$487,813</b>
<b>EXPENDITURES</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>
<b>Administrative Costs</b>			
<i>Secretarial Staff</i>	\$5,000	\$10,000	\$10,000
<i>Professional Staff Salary &amp; Fringe</i>	\$18,340	\$18,340	\$18,340
<i>Advertisement, Brochures, Recruiting</i>	\$8,250	\$6,750	\$6,750
<i>Computer Hardware</i>	\$3,000	\$3,000	\$3,000
<i>Software Licensing</i>	\$2,500	\$2,500	\$2,500
<i>Office Supplies</i>	\$500	\$500	\$1,000
<b>Summer Field Camp</b>			
<i>Professional Staff Salary &amp; Fringe</i>	\$23,211	\$58,693	\$58,693
<i>Food &amp; Housing</i>	\$760	\$30,940	\$42,400
<i>Vehicles</i>	\$2,225	\$5,607	\$7,359
<i>Field &amp; Camping Supplies</i>	\$3,361	\$13,720	\$7,885
<i>Endowment Fund for Underprivileged Students</i>	\$0	\$10,974	\$23,840
<i>Miscellaneous</i>	\$500	\$2,000	\$3,000
<b>Graduate Student Research</b>			
<i>Research Fellowships</i>	\$0	\$46,000	\$92,000
<i>PRC Advisor Salary &amp; Fringe &amp; Travel</i>	\$0	\$5,000	\$10,000
<i>Miscellaneous</i>	\$0	\$1,000	\$5,000
<b>Workshops</b>			
<i>Professional Staff &amp; Fringe</i>	\$14,320	\$20,775	\$20,775
<i>Consultants</i>	\$0	\$3,200	\$6,400
<i>Space Rental</i>	\$1,000	\$2,000	\$3,000
<i>Refreshments</i>	\$500	\$1,000	\$1,500
<i>Miscellaneous</i>	\$500	\$1,000	\$2,000
<b>UMD Geology Courses</b>			
<i>Professional Staff Salary &amp; Fringe</i>	\$3,585	\$14,340	\$14,340
<i>Miscellaneous</i>	\$500	\$1,000	\$2,000
<b>Other</b>			
<i>PRC Reconnaissance Field Research</i>	\$10,000	\$10,000	\$25,000
<i>Advisory Board Meeting &amp; Expenses</i>	\$10,000	\$10,000	\$10,000
<i>Undergraduate Research Grants</i>	\$5,000	\$10,000	\$25,000
<b>SUBTOTAL:</b>	<b>\$113,052</b>	<b>\$288,338</b>	<b>\$401,782</b>
<b>BALANCE:</b>	<b>\$21,948</b>	<b>\$47,680</b>	<b>\$86,031</b>

## 5. PEER INSTITUTIONS

There are currently a number of global mineral exploration research centers that form a network whose aim is to provide expertise across the entire range of mineral deposits research, to aid in the development of collaborative and interdisciplinary research studies in mineral deposits, and to provide logistical support for visiting students and researchers. These centers include the:

*Centre for Ore Deposit Research (CODES)* at the University of Tasmania, Australia

*Centre for Exploration Targeting (CET)* at the University of Western Australia

*Economic Geology Research Unit (EGRU)* at James Cook University, Australia

*Mineral Exploration Research Centre (MERC)* at Laurentian University, Ontario, Canada

*Mineral Deposits Research Unit (MDRU)* at the University of British Columbia, Canada

It's interesting to note that none of these mineral deposit research groups are located in the U.S., the world's largest consumer of mineral resources. Many of the ideas presented in this document concerning the overall plans of the PRC are modeled after these foreign centers of excellence in the field of economic geology. These include the collaborative industry funding, teaching advanced courses in geology at the host college or university, and the development of workshops and shortcourses on advanced techniques in the geosciences. Opportunities exist to integrate the outcome of some components of the goals of the PRC (namely educated geology students with real field skills and experiences) into the advanced degree programs of these Canadian and Australian centers. As well, a strong collaboration with MERC in many geological endeavors is one of the goals of the PRC. The PRC differs from these centers in four basic components, which include the:

- (1) Concentration of research and teaching to Precambrian rocks,
- (2) Concentration of effort on teaching geological mapping, which forms the foundation of all geoscience studies.
- (3) Teaching a Precambrian geology summer field camp for undergraduate students, and
- (4) Utilization of career geoscientists from outside the realm of tenure-track geology professors for a majority of teaching and mentoring,

## 6. EXPRESSIONS OF SUPPORT

The PRC has received strong support from throughout the geological community, which in fact is unanimous from all parties that have received preliminary versions of this document. Current compilations of letters of support are presented in Appendix 5. The geological community that endorses the PRC concept includes the minerals industry (Cleveland-Cliffs Inc., Polymet Mining, Wallbridge Mining, Newmont Mining, Kennecott Exploration, Anglo American Exploration, Franconia Minerals, International Nickel Company), geological surveys (U.S. Geological Survey, Minnesota Geological Survey, Manitoba Geological Survey, Ontario Geological Survey), academia (University of Minnesota Duluth, University of Minnesota, University of Wisconsin Oshkosh, Colorado State University, South Dakota School of Mines and Technology, University of Toronto, Johns Hopkins University, Macalester College, Kent State University), organizations and research centers (American Geological Institute, Fermi National Accelerator Laboratory, Iron Range Resources, National Center for Earth-surface Dynamics), and preeminent economic geology consultants (James Franklin, Odin Christensen, Harold Noyes). The positive responses bode well for achieving the levels of cooperation and collaboration that are essential if the PRC is to make a substantial contribution to reinvigorating the discipline of geological mapping and associated field-based research of Precambrian age rocks.

## **7. ACKNOWLEDGEMENTS**

This proposal could not have been written without the help and insight from a number of individuals. Dean Peterson wishes to thank the NRRI's Steven Hauck and Don Fosnacht for providing the funding to allow me to take the necessary time to write this document. Insight on the current state of geological mapping and geoscience education was provided by many individuals, including Bruce Marsh (Johns Hopkins University), Chris Laughton (Fermi National Accelerator Laboratory), Calvin Alexander (University of Minnesota), Richard Patelke (PolyMet Mining Corporation), Alar Soever (Wallbridge Mining Company), Odin Christensen (consultant), Anthony Naldrett (University of Toronto), Harvey Thorleifson (Minnesota Geological Survey, John Goodge (University of Minnesota Duluth), Vicki Hansen (University of Minnesota Duluth), Mark Jirsa (Minnesota Geological Survey), Jack Parker (Ontario Geological Survey), Peter Jongewaard (Cleveland-Cliffs Inc.). As well, we wish to thank all those involved in writing Letters of Support for the PRC. Special thanks must go out to Pamela Sarvela of UMD's Center for Economic Development for her insight on approaching the writing of this proposal as an integrated Business Plan.

## APPENDIX 1

### Graduate Student Research Themes

UMD's Department of Geological Sciences offers programs leading to the M.S or Ph.D. within the Graduate School of the University of Minnesota. Faculty and students have close working relationships, and programs are tailored to the area of the student's specialization, in consultation with a faculty advisor. The department strives for research that balances field, laboratory, and theoretical studies. Three general types of research projects are envisioned to form the bulk of the PRC-sponsored graduate student research assistantships at UMD: (1) extensive bedrock geological mapping projects that eventually result in the publication of 7.5-minute quadrangle maps; (2) industry-sponsored projects in economic geology or associated fields on existing mining properties and/or mineral exploration projects; and (3) topical field-associated research projects on the Precambrian geology in the Lake Superior region. Preliminary ideas on thesis/dissertation topics are presented below.

**1) Extensive Bedrock Mapping Projects** – These projects could be excellent vehicles for students that desire a career in geological mapping, especially careers in geological surveys or the minerals industry. We envision funding such projects that ultimately result in the publication of 1:24,000 scale MGS or USGS geological maps, and would probably begin in quadrangles that already have some existing detailed geological mapping. Examples of 7.5-minute quadrangles that meet these criteria include the Soudan, Bear Island, Kangas Bay, Chad Lake, and Crab Lake quadrangles.

**2) Industry Sponsored Economic Geology Projects** – These projects are undoubtedly ideally suited for students that desire careers in the minerals industry, and there is currently strong support from this industry to fund projects. Integrated studies utilizing components of diamond drill holes, geological mapping, geophysics, mineral chemistry, rock geochemistry, petrography, and theoretical modeling would be completed in these projects. Examples of proposed projects include:

- The role of micro-deformation features on ore enrichment and metallurgical extraction of iron in the Biwabik Iron Formation (within the context of an overall structural analysis of an open pit mine.)
- Geophysical characterization of Cu-Ni-PGE mineralized zones in the Duluth Complex
- Origin, petrology, and Ni-Cu mineralization in the Tamarack Intrusion
- Hydrothermal alteration and VMS mineralization (Cu-Zn) in the Lower Ely Greenstone
- Structural analysis of the Mud Creek Shear Zone and related structures and their relationship to lode-gold mineralization
- The effects of footwall assimilation on sulfide mineralogy in the basal zone of the Duluth Complex
- Origin of high-level Cu-rich mineralization (South Filson Creek deposit; Magenta Zone, NorthMet deposit; Cloud Zone, Babbitt deposit) in the Duluth Complex
- Geology, petrology and origin of titanium mineralization in the Oxide-Ultramafic Intrusions (OUI) in the Duluth Complex

**3) Topical Research Projects on Precambrian Geology** – These projects are ideally suited for those graduate students that have a strong desire to specialize in a certain aspect(s) of the geological sciences, and the projects would be tailored to the area of the student's specialization. Such projects could include (but certainly are not limited to), Precambrian tectonics, igneous petrology, metamorphic petrology, structural geology, volcanology, hydrothermal alteration, and geochronology.

## APPENDIX 2

### Bedrock Mapping Projects for the Precambrian Field Camp

#### *Neoproterozoic*

- 1) Volcanology and intrusive relationships within portions of the Lower Ely Greenstone
- 2) Geology of the Gafvert Lake Felsic Complex (a sub-vertical dacitic stratovolcano/caldera)
- 3) Structural architecture and gold mineralization within the Mud Creek Shear Zone and related structures
- 4) Geology, metamorphism, and structures of the Vermilion Granitic Complex
- 5) Geology and structure of the metasedimentary Knife Lake Group

#### *Paleoproterozoic*

- 1) Structural geology of the Thomson Formation at Thomson Dam
- 2) Sedimentology of the Biwabik Iron Formation as revealed in active open-pit mine exposures
- 3) Sequence stratigraphy within the Biwabik Iron Formation
- 4) Metamorphism of the Virginia Formation by the Duluth Complex

#### *Mesoproterozoic*

- 1) Geology and igneous stratigraphy of the basal zone of the South Kawishiwi Intrusion, Duluth Complex
- 2) Geology of the Bald Eagle Trough (a macro-dike between the Bald Eagle and South Kawishiwi Intrusions)
- 3) Volcanology and structure of lava flows of the North Shore Volcanic Group
- 4) Geology, structure, and igneous stratigraphy of the Duluth Layered Series in Duluth
- 5) Geology and igneous stratigraphy of the Sonju Lake Intrusion

#### *Quaternary*

- 1) Mapping and determining the environment of deposition of unconsolidated glacial sediments
- 2) Landform mapping

#### *Other*

- 1) Drill core logging and cross section construction for selected mineral deposits/occurrences

## APPENDIX 3

### Implementation Plan

An outline of the plans to implement the PRC into the programmatic elements of the NRRI, MGS, and the Department of Geological Sciences at UMD is outlined below. These plans look outward for three calendar years (to 2008), after which all elements of the PRC will have been established, and we can look forward to continuity of the program into the future.

#### **1. 2006 (PRC Planning, Initial Shortcourse)**

- a. Securing letters of support from industry
- b. Securing graduate student support from the College of Science & Engineering at UMD
- c. Secure funding from a variety of sources
- d. Recruit a Board of Advisors, host first board meeting
- e. Presentation of PRC program to faculty from geology departments from Minnesota State Colleges and Universities (MNSCU) and other University of Minnesota campuses
- f. Pass the new geology courses through the Curriculum Committee at UMD
- g. Develop geological science plan for graduate student research projects
- h. Teach initial shortcourse on “Integration of Field Geological Data into a GIS system”
- i. Meet with federal representatives of the U.S.D.A. concerning geological mapping in the BWCAW
- j. Reconnaissance investigation of wilderness mapping project areas in the BWCAW
- k. Development of mapping keys for field camp “small mapping projects”
- l. Acquisition of field and office supplies needed for field camp
- m. Plan programmatic elements of the summer field camp (projects, utilize MNSCU facilities, faculty, etc.)
- n. Advertise the PRC program to the geological community

#### **2. 2007 (Initiation of Summer Field Camp, Graduate Student Scholarships)**

- a. Teach 1<sup>st</sup> annual Precambrian Summer Field Camp
- b. Fund the first two geology graduate students at UMD
- c. Host a planning meeting of the Board of Advisors and PRC staff and collaborators
- d. Teach several shortcourses on topics in Precambrian Geology
- e. Acquire more funding
- f. Advertise the PRC program to the geological community

#### **3. 2008 (Fully Developed Program)**

- a. Host a review meeting on the previous years field camp (how to improve)
- b. Teach 2<sup>nd</sup> annual Precambrian Summer Field Camp
- c. Teach courses in geology at UMD
- d. Fund two additional geology graduate students at UMD
- e. Teach several shortcourses on topics in Precambrian Geology
- f. Publish first 1:24,000 scale geology map integrating field camp student mapping
- g. Write a journal article on the field camp experience to the Journal of Geoscience Education, the SEG Newsletter, and/or GSA Today.
- h. Advertise the PRC program to the geological community

## APPENDIX 4

### Biographical Sketches of PRC Directors and Invited Board of Advisor members

**Dr. Peterson** is an economic geologist with broad experience in geological mapping of rocks of all types and ages, and has worked in and with the mineral exploration industry in search of mesothermal-gold; epithermal-gold; volcanogenic massive sulfide; copper-nickel-platinum group element (PGE); high-grade copper-PGE veins beneath the Sudbury Igneous Complex; and copper-gold-molybdenum porphyry deposits. His research interests include economic geology, geological mapping, Precambrian geology, mineral potential modeling, and three-dimensional modeling of ore systems. He has spent portions of four summers on the faculty of the Wasatch-Uinta geology field camp, and has taught courses in the Department of Geological Sciences at UMD on Field and Computer Methods in Geology, Earth's Resources, and Archean Lode Gold Deposits. Dean has worked extensively in the National Science Foundation's initiative to develop a Deep Underground Science and Engineering Laboratory (DUSEL) in the United States, first as a Principal Investigator for the University of Minnesota's proposal for the Soudan Mine, and currently is collaborating with the DUSEL teams associated with the Homestake and Henderson mines.

**Dr. Miller** is an igneous petrologist whose major emphasis of research has been field, petrologic, and metallogenic studies of the igneous rocks of the 1.1 billion-year-old Midcontinent Rift. Specifically, Jim's work focuses on producing bedrock geologic maps of the Duluth Complex and related intrusive terranes of the Midcontinent Rift in northeastern Minnesota; studying the petrology and crystallization history of various intrusions within the Midcontinent Rift; evaluating the potential for economic mineralization within these intrusions, especially with regard to platinum group minerals; and, overall, investigating the general tectonic and magmatic history of the Midcontinent Rift. Another major focus of Dr. Miller's work with the MGS involves educational outreach. He frequently speaks to school groups, teaches non-credit classes (Complete Scholar and ElderHostel), leads field trips in an attempt to introduce Minnesota geology to non-geologists, and has been actively involved in planning and implementation of workshops for K-12 earth science teachers for several years.

## Biographical Sketches of the Board of Advisors

### *James M. Franklin*

Jim Franklin is a consulting geologist with over 35 years of experience in the study of mineral deposits and regional metallogeny. He is a graduate of Carleton University (B.Sc.(64); M.Sc. (67)) and received his Ph.D. from the University of Western Ontario in 1970. He taught at Lakehead University from 1969 until 1975. From 1975 until 1993, Jim worked for the Geological Survey of Canada (GSC) where he developed a regional metallogenic framework for Southern, Churchill and Superior provinces of the Canadian Shield. He directed major research programs on gold deposits in southern Churchill Province, and VMS deposits in Churchill and Superior provinces. From 1983 until 1993, Franklin was director of the GSC's Seafloor Minerals Program, which culminated in two legs of Ocean Drilling Program (ODP). He was one of the first geologists to use a deep submersible to study "black smokers" on the mid-ocean ridges. As chief geoscientist of the GSC from 1993 until 1997, Dr. Franklin was responsible for directing the GSC's entire scientific program, including activities within multilateral national and international scientific programs and for setting priorities for geoscience programs within the Government of Canada. He retired from the GSC in 1998 and is now working as a consulting geologist.



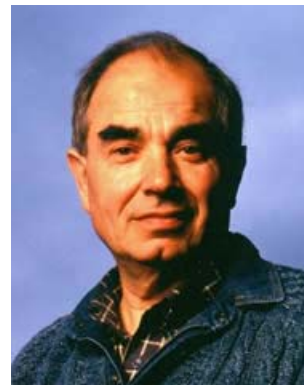
Currently, Jim is a director or science advisor on the boards of six mineral exploration companies and one hydrocarbon producer, and sits on numerous boards for professional and scientific groups. His consulting work is focused on new discoveries of volcanogenic massive sulfide deposits, orogenic and porphyry-style gold in Precambrian terrains, and magmatic nickel-copper sulfides.

Franklin is a Fellow of the Royal Society of Canada, and represents Canada's geoscientists on the Partnership Group for Science and Engineering. He is a registered professional geologist in the province of Ontario, and an Adjunct Professor at Queen's and Laurentian Universities. He is co-editor of Exploration and Mining Geology for CIM, and was Associate Editor of Economic Geology for seven years. He is a Past President of both the Geological Association of Canada and the Society of Economic Geologists. In addition to his Fellowship in the Royal Society of Canada, he was awarded the Michel T. Halbouty Award from Geological Society of America (GSA) in 2002, the Canadian Institute of Mining, Metallurgy, and Petroleum's (CIM) A.O. Dufresne Award in 1995, the Duncan R. Derry award by Geological Association of Canada (GAC) in 1992, the Thayer Lindsley Award by Society of Economic Geologists (SEG) in 1990 and the SEG's Distinguished Lecturer Award in 1988. He has published over 125 papers and book chapters, and over 100 abstracts.

## Biographical Sketches of the Board of Advisors

### *Anthony J. Naldrett*

Anthony J. Naldrett (Tony) was born in England and received his degree in geology from the University of Cambridge in 1957. The same summer he emigrated to Canada, and worked for several years as a geologist for Falconbridge Nickel Mines Ltd. in Sudbury. In 1959 he left full time employment with Falconbridge to attend Queen's University, to conduct research on Ni deposits, receiving his M.Sc. in 1961 and Ph.D. in 1964. After 3 years in Washington at the Geophysical Laboratory, he returned to Canada as Assistant Professor at the University of Toronto in 1967. He retired from the University of Toronto in 1998 and is now Emeritus University Professor. In addition, he received D.Sc. (honoris causa) awards from both Laurentian University and University of Pretoria in 2000 and 2001, respectively. Tony and his students/research associates at the University of Toronto have worked on the geology, mineralogy and chemistry of magmatic sulfide deposits and related rocks. He has authored, or co-authored along with his students and colleagues, 240 refereed publications, plus the writing or editing of 8 books. Tony is the world's foremost authority on the geology and origin of nickel-copper-platinum group element deposits, the tectonic setting in which they occur, the petrology of associated rocks, and controls on their composition (reaction between sulfide and silicate melts; fractional crystallization of sulfide melts; the role of hydrothermal fluids). Tony's research has covered most of the world's magmatic sulfide ores, including those at Sudbury, the Abitibi Belt, Voisey's Bay, the West Australian Komatiite deposits, the Zimbabwe Ni deposits, deposits of the Raglan and Thompson Nickel belts, Noril'sk, Pechenga, Jinchuan, the Duluth Complex, the Bushveld and Stillwater complexes, the Great Dyke, and at Lac des Iles. He has also taken an interest in chemical processes related to magmatic sulfides, including work on the Fe-S-O and Fe-Ni-S systems, sulfur solubility in silicate melts, the activities of divalent cations in mafic melts, partitioning of Ni, Cu, Co and PGE between sulfide and silicate melts and between monosulfide solid-solutions and sulfide melts.



In addition to his research, he has served as consultant to many companies including Chevron, Falconbridge Ltd., MRDI, Western Mining Corporation, BHP-Billiton, Rio Tinto, Diamond Fields Resources, Cominco-American, Kennecott, MRDI, Donner Minerals, and Anzex Resources Ltd.

Apart from academic studies, Tony has played a role in several scientific societies, becoming President of the Mineralogical Association of Canada (1982-83), the Society of Economic Geologists (1991-92), the International Mineralogical Association (1998-2002), the Geological Society of America (2001-2002) and Chairman of the Board of the International Geological Correlation Programme. His honors include appointment as University Professor of the University of Toronto (1984), election to Fellowship in the Royal Society of Canada in 1984, Honorary Life Fellowships in the European Union of Geosciences (1983), Russian Mineralogical Society (1999) and Mineralogical Society (2002), the Barlow Gold Medal of the Canadian Institute for Mining and Metallurgy (1974), the Bownocker Gold Medal of Ohio State University (1986), the Duncan Derry (1980) and Logan Medals (1994) of the Geological Association of Canada, the Society (1982) and Penrose Gold (2002) Medals of the Society of Economic Geologists, and the Past-Presidents' Medal of the Mineralogical Association of Canada (1991).

## Biographical Sketches of the Board of Advisors

### *Odin D. Christensen*

Odin Christensen has realized a distinguished career in mineral exploration and is considered an authority on gold deposits, particularly Carlin-type deposits. Those who have worked with him know him to have particular conviction to the protection of and respect for people, communities, and the environment. He is proud to be a field geologist, having made career choices that have kept him close to the rocks. A native of Duluth Minnesota, Odin received a BS degree in Geology from the University of Minnesota Duluth and PhD in Geology from Stanford University. He began his career as Assistant Professor of Geology at the University of North Dakota, covering the disciplines of mineralogy, geochemistry, and economic geology. He then moved to the Earth Science Laboratory at the University of Utah Research Institute, working on geochemical characterization of active geothermal systems, with emphasis upon the development of exploration technology.



In 1981, Odin joined Newmont Exploration in Reno Nevada as a Research/ Project Geologist, involved in exploration for gold, silver, and tungsten in the Great Basin and Cordillera. In 1985, he was appointed Newmont's exploration manager on the Carlin trend, Nevada, and over the next 6 years guided the incredibly successful exploration program that transformed Carlin from a couple of small gold mines into one of the world's premier gold producing districts. In 1992, Odin was appointed Chief Geologist for Newmont Mining Corporation, responsible for technical guidance of the company's worldwide exploration and mine geology programs. Notably, this included active participation in the early exploration and development of Yanacocha Peru, Mesel and Batu Hijau Indonesia. In 2001-2002, Odin was Exploration Manager for Empresa Minera Inti Raymi, based in La Paz Bolivia, responsible for mine geology at the Kori Kollo mine and exploration within Bolivia. He is credited with recognition of the Kori Chaca deposit. Odin is currently an independent consulting mineral geologist living in Mancos Colorado.

Odin is a Fellow of the Society of Economic Geologists and Geological Society of America; a member of the Society of Mining Engineers, American Institute of Professional Geologists (Certified Professional Geologist), Society for Geology Applied to Mineral Deposits, Geological Society of Nevada, and Four Corners Geological Association. Odin was recognized as a Thayer Lindsley Lecturer for the Society of Economic Geologists, was awarded the Ben F. Dickenson Award from the Society for Mining, Metallurgy and Exploration Inc., and was honored as the inaugural Ralph Roberts Lecturer at the University of Nevada Reno. In 2004, Odin was inducted into the Academy of Science and Engineering at the University of Minnesota Duluth. He has served on committees of the National Academy of Sciences and has testified before Congressional committees. He is the author or editor of numerous professional papers and guidebooks, and served as an Associate Editor of *Mineralium Deposita*.